European Commission

Nuclear activities

of the Joint Research Centre

Seventh Framework Programme

European Atomic Energy Community (Euratom)

Annex 1: Action reports

2015

Index of the Reports

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action *51102 NWD / NMD2*

Nuclear Waste Disposal (and Decommissioning)

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0. Policy Area

5 – The EURATOM Programme, Nuclear Safety and Security

5.1 - Nuclear Waste Management and Environmental Impact

5.1.1 – Spent Fuel Characterization, Storage and Disposal

1. Rationale of the Action:

The rationale for the Nuclear Waste Disposal and Decommissioning (NWD2) (until 2012 “Nuclear Waste Disposal (NWD)) action is that safe and responsible long-term management of toxic and radioactive wastes is an ethical obligation of each Member State in order to avoid undue burdens on future generations. Radioactive waste is not only generated in those states that use nuclear energy for electricity generation, but also by many other applications, be it radiotherapies or industrial tests. Its safe management is therefore a challenge for all Member States, irrespective of their stance on nuclear.

While low and medium level radioactive waste is increasingly being taken care of, there is not yet a single final repository for high-level radioactive waste and spent fuel. It is likely, how-ever, that the first such repositories open before 2030 in some EU Member States.

In July 2011, the Council adopted the Directive 2011/70/EURATOM on responsible and safe management of spent fuel and radioactive waste. With this adoption, the Directive entered into force in September 2011, obliging Member States to transpose the Directive in 2013 and notify national programmes to the Commission in 2015.

Each Member State remains free to define its own policy and for nuclear waste management related to power reactors. The strategy adopted by most countries is direct disposal of the spent nuclear fuel. All Member States must have national frameworks and programs for the management of all types of radioactive waste and spent fuel. Particular challenges are especially encountered where the national programmes are phasing out, or are less extended and less advanced. Especially under these circumstances, access to competence, infrastructure, analytical methods, training opportunities and knowledge on a European level becomes increasingly crucial.

The JRC, independent of national and commercial interests, and specifically the NWD2 Action assists DG ENER and the Member States in implementing the Directive. Through its extensive R&D activity in the field, the Action provides for continuous improvement and for evidence of safety of nuclear waste disposal, dissemination of scientific achievements, training and education to maintain and develop a high degree of competence. In addition, it provides access to its advanced infrastructure and competence to Member States, research consortia and European and international collaboration partners. Provision and development of infrastructure also includes state of the art experimental facilities and analytical methods, especially where this is difficult or non-practicable in the Member States themselves.

2. History and development of the Action:

The Action has its focus on R&D for identifying and studying key processes relevant for safety in storage and disposal of spent nuclear fuel (irradiated U dioxide and mixed U-Pu oxide, or MOX). Spent nuclear fuel concerns all Member States with nuclear power generation and is the key high-level heat generating radioactive waste in case of direct disposal scenarios. Relatively less emphasis is devoted to other forms of heat generating high-level radioactive waste, in particular glass waste forms from spent fuel reprocessing. For these waste forms, targeted research projects have been implemented, mainly in the frame of bilateral partnerships with Member States research organizations and universities. The main evolution of the Action reflects the renewed or increased relevance of areas such as extended spent fuel storage and retrievability thereafter, handling/conditioning of damaged spent fuel, and decommissioning. The accident at the Fukushima-Daiichi in 2011 has dramatically brought to attention several topics, including (within the scope of the present Action) the corrosion behaviour of damaged/molten fuel debris in seawater and other aqueous media, the retrieval and conditioning of the debris, and the decommissioning and remediation of facilities affected by severe accidents. Since 2012, the Action includes decommissioning R&D aspects in its portfolio, in consideration of the fact that a major source of radioactive waste will arise in the coming decades, namely from decommissioning of a vast, progressively ageing nuclear power plant fleet. Last, but not least, in order to give more prominence to the use and transfer of knowledge to Policymaking at Member State and European levels, a Policy Support line was specifically defined in the work programme of the last three years of the Action (2011-2013).

The main emphasis in the Action was and remains on R&D in order to develop the scientific-technical basis for responsible and safe management of critical forms of radioactive waste. This knowledge and development is an important element also in supporting implementation of legal and regulatory instruments.

Waste forms

Investigations on spent fuel have evolved in order to reflect the progressively higher burn-up of commercial spent fuel, associated with higher heat-load and a higher degree of heterogeneity (characterized by the presence of different mineralogical structures, physical and chemical properties and fission products distributions) compared to low burn-up spent fuel. Effects were addressed associated to different irradiation histories and to different compositions, including neutron economy regulating chemical additives. Dedicated work has investigated spent MOX fuel. Such spent fuel was originally not foreseen for direct disposal. In Member States where reprocessing options were abandoned due to changes in the fuel cycle strategy, however, the end-point for spent MOX fuel has become geologic disposal. In comparison with UO2 fuel, MOX is characterized by higher actinide content with a different isotopic vector, higher heat-load and particular physical and mineralogical configurations. Towards the end of FP7, and in response to needs relevant for the safety case of disposal concepts in Member States, the work has evolved to include also other waste forms than spent fuel, especially in relation to presence and behaviour of radionuclides such as 14C, 79Se, 126Sn, 129I for which presently no sufficient knowledge and/or technologically mature disposal solutions are available.

Storage and Retrievability

The end-point of radioactive waste management is disposal, i.e. emplacement of the waste where the living environment is protected by passive and robust safety features. Prior to disposal, radioactive waste and, in particular, spent fuel is stored either awaiting the required disposal options or in order to decrease the heat level and radiological content. Experience shows that the lead-times for implementing disposal options become longer than originally planned for. Consequently, the structural integrity of spent fuel in storage and its retrievability thereafter needs to be demonstrated for much longer times than planned for in the past. For this reason, the Action work programme has developed towards more emphasis on the stability and structural integrity of spent fuel in relation to extended storage. The scope includes normal evolution of spent fuel rod properties and behaviour under accident conditions. This is also relevant for the progressive inclusion of retrievability and recoverability in national regulatory frameworks for disposal of spent fuel.

Damaged spent fuel material

Handling, drying, storage, transportation of damaged spent fuel rods is a new area of investigation which started near the end of the reporting period. The relevance of this topic stems in particular by the need to empty the spent fuel pools at the reactor sites in countries where nuclear energy is phasing out (e.g. Germany), but is also of relevance in Member States where there is a legacy of damaged or potentially damaged spent fuel in need for further handling and conditioning. A set of studies, linked to the decommissioning and to the severe accident topics has been discussed and is currently being implemented.

Post-Fukushima activities

After the Fukushima accident, several activities were initiated to address topics related with fuel degradation/melting behaviour and properties and also with an eye towards future damaged fuel/debris retrieval and conditioning, and reactor decommissioning and remediation. JRC-ITU has a strong background of expertise in the severe accident domain, having participated in the main international projects which started after the Three Mile Island 2 accident. The severe accident domain is a component of the Action "Safety of Nuclear Fuel and Fuel Cycles", and some of the post-Fukushima R&D activities are included there. However, the investigations more related with spent fuel retrieval, conditioning and decommissioning are within the scope of the present action. The new activities are closely linked to the investigations on spent fuel safety during storage, transportation and disposal.

The expertise deriving from the performance of many campaigns to investigate the leaching behaviour of spent fuel in (ground) water has been applied to study the corrosion behaviour of damaged spent fuel material / debris in aqueous media. During the reporting period focus was on specific aspects that characterized the Fukushima accident, namely, damaged/molten fuel corrosion in sea salt solution. Ongoing projects aim at extending the scope of these studies to cover remediation and decommissioning aspect associated with a severe accident.

Decommissioning

Large amounts of radioactive waste will arise from decommissioning of nuclear facilities in the coming decades. It is foreseen that decommissioning of the ageing nuclear reactors fleet in Europe will generate a multi-billion Euro market. In order to contribute to well positioning and competitiveness of the European industry in this

area, and also to contribute to safety and standardization aspects, it was decided that JRC shall participate in this domain. The JRC Decommissioning Research and Development Programme (DWM-R&D) was developed and integrated as part of the scientific programme during the extension of the Euratom 7th Framework Program 2012 and 2013 and is within the Key Orientations of the JRC for the Horizon 2020. Correspondingly, scoping discussions and analyses identified the own operational decommissioning work and the application of specific tools developed in JRC to characterize waste from decommissioning as relevant areas of expertise. This work paved the basis for presently ongoing activities related to several fora, involving regional competence clusters and universities. The involvement foreseen includes R&D projects and applications, education and training, knowledge management and information exchange.

Analytical Methods and Designed Samples

Analytical and specific experimental methods for solid state and solution analysis are developed and refined as a key component in support of the scientific-technical progress across the different topics. The key challenge is the application of the analytical methods and systems to highly radioactive samples. Topical areas include characterization of surface properties and processes, accessibility of surfaces to water, spent fuel corrosion mechanisms in groundwater, routes for diffusion of volatile components to the environment. A broad set of methods is used, such as electrochemistry, isotope markers and depth profiling, and topographic characterization. Systems combining different methods are also important, e.g. chromatographic coupling with ICP-OES. The most prominent example is combination of a broad set of (micro) analytical methods in one integrated laboratory station.

In addition to irradiated fuel and active waste forms, well characterized simulated fuel and ad hoc samples (e.g. alpha-doped materials, model fuels, thin films, nano-particles) are used.

Policy support

The key driver of this field of activities was the negotiation of the Council Directive 2011/70/EURATOM on responsible and safe management of spent fuel and radioactive waste. Other activities in support of knowledge and information management related to the Commission Indirect Action programme are also included. Finally, support to external policy activities is also included under this title (support to for example IAEA, OECD-NEA and the European Nuclear Energy Forum).

3. Description of the Action

The following sections describe: Clients and stakeholders, followed by Objectives and their respective Deliverables and Impacts, and finally Further Information. The latter is sub-divided into Integration and Networking, Competitive Actions and Mobility and Training. The Objectives follow a structure close to that used towards the end of the Action where R&D objectives are grouped together according to their nature, function and role in the Safety Assessment.

3.1. Clients and Stakeholders

Key Clients and Stakeholders are listed in the table below. Universities are not included. Furthermore, not all partners of project consortia are listed but only those where a direct cooperation took place.

Key Clients and Stakeholders	
European Commission	DG ENER, DG RTD
International organizations	IAEA (International Atomic Energy Agency), EASAC (European Academies Science Advisory Council), GIF (Generation IV International Forum), IGD-TP (Implementing Geological Disposal – Technology Platform), OECD-NEA (Organisation for Economic Co-operation and Development)
R&D organizations in EU Member States	CEA (Commissariat à L'Energie Atomique, FR), CIEMAT (Centro de Investigationes Energéticas Medioambientales, ES), CNRS (Centre Nationale de Recherche Scientifique, FR), FZJ (Forschungszentrum Jülich, DE), KIT (Karlsruher Institute of Technology, DE), ICSM (Institut de Chimie Séparative – Marcoule, FR), NNL (National Nuclear Laboratory, ex-Nexia Solutions – British Nuclear Fuels plc., UK), NRI – REZ (Nuclear Research Institute in Rez, CZ), PSI (Paul Scherrer Institut, CH), SCK/CEN (Belgian Nuclear Research Centre, BE), Studsvik Nuclear AB (SE),
Industry	AREVA (FR-DE), GNS (Gesellschaft für Nuklear-Service, DE), Cavendish Nuclear (ex-UKAEA – Babcock, UK)
Technical safety organizations, National Agencies, Nuclear waste organizations in EU Member States	IRSN (Institut de Radioprotection et de Sûreté Nucléaire, FR), BAM (Bundesanstalt für Materialforschung, DE), NDA (Nuclear Decommissioning Authority, UK), ENRESA (Empresa National de Residuos Radioactivos, ES), NAGRA (Nationale Gesellschaft für die Lagerung Radioaktiver Abfälle, CH), SKB (Svensk Kärnbränslehantering AB, SE)
Organizations outside the EU: Research, Technical safety organizations, Regulators, Industry	NRC (Nuclear Regulatory Commission, US), US-DOE (US Department of Energy) National Laboratories: PNNL (Pacific Northwest National Laboratory), ANL (Argonne National Laboratory), INL (Idaho National Laboratory), LANL (Los Alamos National Laboratory), NRCN (Nuclear Regulatory Centre Negev, IL), CRIEPI (Central Research Institute of Electric Power Industry, JP), JNFL (Japan Nuclear Fuels Limited, JP),

3.2. Major Objectives, deliverables and impacts

Objective 1: Development of Analytical Methods

Often knowledge gaps are associated to or caused by the lack of suitable analytical methods. The development of state of the art analytical methods in support of the R&D work is thus a key task. A complication affecting experiments in this field is the necessity of developing and adapting specific advanced analytical tools for application in hot cell or other shielded facilities remotely operated by telemanipulators. An infrastructural environment such as that at JRC-ITU allows the successful tackling of this kind of challenges. This line of activities is linked to all other experimental objectives.

Deliverables and Impact

Analytical developments are:

i. Building an Advanced Modular Surface Characterization Lab which combines several surface characterization methods in one integrated system, namely AFM, HREELS, TPD, PES, BIS, LEED, thin film deposition and reaction. The modular configuration of this system enables multiuser-multitask operation.

ii. Development of electrochemical electrodes for measurement of hydrogen gas in aqueous solution under highly radioactive/radiolytic field conditions.

iii. Develop electrochemical methods for the determination of surface corrosion processes and mechanisms on spent fuel analogues.

iv. Electrochemical Quartz Crystal Micro Balance system for surface process studies on actinides/transuranium compounds.

v. Raman spectroscopy adapted to radioactive materials

vi. Determination of water penetration mechanisms into UO2 crystals based on SIMS analysis of 18O depth gradients (using 18O-labelled water)

vii. ICP-OES and HPLC-coupled ICP-MS for spent fuel leachate analysis

viii. Sequential separation procedure for ultra-trace analysis of Po, Ra, U and Pu – Migration patterns using accelerator mass spectrometry.

ix. Coupling of chromatographic methods with ICP-MS for instant release fraction analysis

Impact. By making available these analytical methods, elusive or ultra-low concentration species (and their speciation) will be characterized. In-situ investigation of surface corrosion mechanisms and water penetration in corroding fuel will be possible. The outcome of the investigation projects will be available to the scientific and stakeholder community. The facilities will be made available for joint projects and access by interested partners.

Objective 2: Preparation of samples with designed properties

Tailor-made analogue samples mimicking specific compositional or phase distribution features in high level waste / spent fuel are prepared. For instance, such analogues mimic aspects of MOX spent fuel configuration, single out the radiation damage effects due to alpha-decay, or reproduce the progressive oxidation of spent fuel matrix material. They enable single effect studying of specific mechanisms and processes where the "real" material (e.g. spent fuel) is not suitable for the envisaged measurement device (due to its radioactivity) or prohibitively complex to determine unequivocal cause-effect relationships. This line of activities is linked to all other experimental objectives, especially the instant release fraction (objective 4) and the fuel matrix dissolution (objective 5).

Deliverables and Impact

Samples with designed properties developed and prepared are in particular:

i. Oxide compounds doped with 238Pu for TEM analysis of alpha-decay effects on the spent fuel matrix

ii. U-Pu and U-Th thin oxide films with different oxygen content

iii. UO2 thin films doped with Pd and Mo (typical constituents of metallic precipitates present in spent fuel)

Impact. Data and understanding of key processes which may affect spent fuel over long-term are generated. In combination with "integral" data from spent fuel experiments, results from tailor-made analogue testing provide insight to identify and characterize mechanisms that will govern the properties of spent fuel of different composition, burn-up and irradiation history. This knowledge will contribute to reducing uncertainties affecting the prediction of spent fuel behaviour over long-term time intervals.

Objective 3: Long-Term Storage Integrity of Spent Fuel

Investigations are conducted with the aim of being able to predict the stability and structural integrity of spent nuclear fuel. This refers both to the stability in handling spent fuel after several decades or even hundreds of years in storage, and to the stability and structural integrity in case of retrieval of the spent fuel canisters after decades or centuries in a repository. The studies cover also the potential radionuclide release to be expected in case of accidents involving the breach of spent fuel rod cladding (link with instant release fraction studies – objective 4). Possible degradation of the mechanical integrity of the fuel over the very long term may cause a significant increase of surface area. In case of spent fuel in a geologic repository, this may affect the corrosion behaviour of the fuel in contact with groundwater (link with fuel matrix dissolution studies – objective 5).

Deliverables and Impact

i. Determine the effects of radiogenic helium accumulation (e.g. during extended storage) on spent fuel pellet structure and mechanical properties. Property alterations as a function of time are measured for spent fuel and unirradiated PuO2 and □□doped UO2. He solubility in UO2 was studied. Helium accumulation in the spent fuel matrix, and diffusion pathways for its release are assessed. Potential mechanisms for structural deterioration through stress build-up, self-healing and recovery or mobility of defects are studied.

ii. Develop and apply first principle calculations for the behaviour of fission gases in spent fuel, including UO2, UN, (U, Zr)N and MOX.

iii. Assess fuel release and dispersion behaviour in the extreme case of an accident involving spent fuel rod breach.

Impact. The results of severe impact tests on spent fuel from PWR and BWR with burnup between ~20 and ~74 GWd/tHM show that only the volume of fuel directly affect by the rod fracture is released. No "flow-out" of the fuel occurs. These results addressed a concern by the licensing authority concerning safety of spent fuel transports. Studies to extrapolate the potential evolution of spent fuel during extended storage using a combination of spent fuel and alpha-doped analogues identified only excess fuel swelling induced by helium accumulation as potential concern. Further work will clarify this open issue. The data collected so far are used by regulators (e.g. NRC) in calculations to try and predict long term behaviour of spent fuel during storage. Helium solubility in UO2 was characterized.

The overall impact of the investigations is improve knowledge and tools for predicting the long-term stability and integrity of spent nuclear fuels during extended storage. This contributes to define safe procedures when storage times are extended well beyond original planning, i.e. to which extent the spent fuel then can be safely transferred to disposal canisters or not. Furthermore, it has a strong impact on decisions for provision of retrievability and recoverability of disposed spent fuel.

Objective 4: Spent Fuel Instant Release Fraction

The instant (or fast) release fraction signifies the fraction of radionuclides inventory that escapes from spent fuel upon first contact between fuel and (ground)water prior to release of radionuclides through dissolution of the spent fuel matrix. The instant release fraction is the contributor to peak dose in a distant future in the case of spent fuel disposed in the geologic repository. In order to develop predictive tools, also the accessibility to water and diffusivity of mobile instant release fraction isotopes in different parts of spent fuel pellets is needed. This line of investigation is linked to the analysis of source term for "instant" radionuclides release in accidents involving cladding failure (link to objective 3).

Deliverables and Impact

The deliverables include:

i. Determination of the instant release fraction for spent UO2 and MOX fuel by short-term leaching experiments; comparison with Knudsen cell thermal release tests performed before and after leaching.

ii. Determination of instant release fraction associated to different regions of a spent fuel pellet (centre, periphery, cladded segments).

iii. Determination of instant release fraction associated to different burn-ups and irradiation histories.

iv. Investigate thermal annealing impact on instant release fraction (Knudsen cell tests)

v. Determination of distribution and diffusion properties of volatile species (e.g. Cs) in spent fuel matrix and grain boundaries/surfaces and in different radial region of a pellet (combine experimental and modelling effort)

Impact. The experimental data show that the rim region of spent fuel pellets, where a high concentration of fission products, plutonium and minor actinides occurs and where a new structure is formed during irradiation, does not present higher release rates with respect to other regions of the fuel. Moreover, the instant release fraction measured experimentally corresponds only to a few % of the local inventory of mobile radionuclides (e.g. Cs). The data clearly indicate that conservative assumptions (e.g. assuming an instant release fraction of 100%) are unjustified.

Reducing uncertainties in the value of instant release fraction reduces conservatism in design and safety assessment of geologic repository disposal with respect to the most critical release for peak-dose expected to appear in a distant future. This provides better confidence and results in the optimization of the use of resources for a repository.

Objective 5: Dissolution of Spent Fuel Matrix

The dissolution of spent fuel is governed by the oxidation of the UO2 fuel matrix. The solubility of higher oxide forms of uranium is several orders of magnitude higher than that of stoichiometric UO2. By the oxidative dissolution of the matrix, other radionuclides become accessible for dissolution. A common feature of European geologic repository concepts is the presence of chemically reducing conditions, which is beneficial to avoid oxidative dissolution. The actual matrix dissolution rate

will be governed by the limitation in diffusion of oxidative species to the waste, and the consumption of these species. These species will be consumed especially by corrosion of iron canister material. Iron will react with water and oxidize, causing the build-up of hydrogen overpressure in the deep repository environment. Factors potentially altering this beneficial condition are investigated. In particular, the contrasting effects due to water radiolysis (potentially enhancing dissolution) and the hydrogen overpressure (suppressing corrosion) are investigated. Additional effects related e.g. to the surface area of spent fuel accessible to groundwater are considered. The surface area would be increased significantly if the mechanical integrity of the fuel is compromised by very long term accumulation of radiogenic helium (link with objective 3)

Deliverables and Impact

The deliverables can be summarized as:

i. Determination of matrix dissolution behaviour of UO2, ThO2, PuO2, irradiated UO2 and MOX fuel with varying burn-up, composition and irradiation history under controlled chemical conditions (leachant composition, redox conditions).

ii. Determination of dissolution processes by for example electrochemical investigations on tailor-made material (link with objective 2) e.g. by the use of thin-film model systems (ThO2, UO2, PuO2 and MOX including selected fission products).

iii. Description of the oxidation behaviour of the spent fuel matrix material (UO2+x and PuO2+x) in terms of mechanistic process understanding and provision of data for predictive modelling.

iv. Penetration of water into spent fuel matrix material by isotope gradient investigations using SIMS analysis.

v. Characterization of the process and explanation of the mechanisms involved in the hydrogen corrosion suppressing effect occurring in deep anoxic repository conditions, including clarification of surface catalytic processes, e.g. associated with noble metal inclusions, for the effective reduction by dissolved hydrogen gas.

Impact. The beneficial effect of hydrogen in a repository near field with respect to inhibition of spent fuel matrix dissolution is now taken into account in the safety assessment for the geologic repository. This effect has been characterized on spent fuels (UO2, MOX) and on alpha-doped analogues. Extent and relevance of alpha-radiolysis dissolution-enhancing effects have been investigated. A threshold for this effect (under the experimental conditions considered) has been identified and translated into spent fuel age. This provides an indication of the temporal extent during which radiolysis would be expected to play a role in determining the dissolution mode for spent fuel in a repository.

Similarly to the case of instant release fraction studies, reduction of uncertainty in safety assessment predictions has positive impact on the confidence the predictions and on repository design optimization. This is the sum of progressive understanding and access to data for the different key safety relevant processes. The exact mechanisms, however, are not yet fully understood. Clarification of these mechanisms will have a further strong impact on trust in the present safety predictions.

Objective 6: Leaching of damaged spent fuel material in seawater and other media

After the Fukushima accident, JRC-ITU expertise deriving from the performance of many campaigns to investigate the leaching behaviour of spent fuel in (ground) water was applied to investigate the corrosion behaviour of spent fuel debris in seawater and other media relevant for the aftermath of the accident. An important feature of this work is that the tests are performed using spent BWR fuel and also corium debris from the damaged core of the Three Mile Island 2 reactor available in JRC-ITU's hot cells. Part of this work is performed in collaboration with the Central Research Institute of Electric Power Industry (CRIEPI) of Japan.

Deliverables and Impact

The results obtained so far show limited differences in radionuclides release behaviour between seawater and demineralized water. Evidence for secondary phase formation was obtained.

Impact. As this line of activities is still ongoing, a limited set of data has been produced during the reporting period. The data are of high relevance for the Japanese government and for the local utilities, to whom they are reported by the CRIEPI colleagues. Some data have been presented at IAEA International Expert Meetings and other fora.

Objective 7: Decommissioning

During the work programmes 2012 and 2013, scoping discussions and analyses were implemented in order to define the potential involvement of JRC in decommissioning R&D. The own operational decommissioning work and the application of specific tools developed in JRC to characterize waste from decommissioning were identified as relevant areas of expertise. Handling, drying, storage, transportation of damaged spent fuel rods is an additional new area of investigation which started near the end of the reporting period and which is closely linked to the decommissioning area.

Impact

The scoping work paved the basis for presently ongoing activities which are related to several fora, involving regional competence clusters and universities. In particular, in 2014 JRC was asked to join the "Upper-Rhine Competence Cluster on Decommissioning", a regional initiative launched by the government of Baden-Württemberg (Germany) and involving industry, universities, local governments and research organization from Baden-Württemberg, Alsace (France) and northern Switzerland. Other links were established, e.g. with the University of Birmingham (UK). Contributions to IAEA (through Coordinated Research Projects proposals) are launched. The foreseen JRC contributions will include R&D projects and applications, education and training, knowledge management and information exchange.

Objective 8: Policy Support

The ITU is providing support to the Member States through different DG’s, as well as to international organizations, in order to promote integration, harmonization and dissemination of good practices and knowledge. In particular this refers to implementation of the Waste Directive (Council Directive 2011/70/EURATOM). The

IAEA is receiving support with development of relevant technical documents and assessment of the waste safety work programme.

Deliverables and Impact

The Deliverables can be summarized as:

i. Through support to the European Nuclear Energy Forum (ENEF), Guidance to the Member States for implementation of the Waste Directive, resulting in publication of "Guidelines for the establishment and notification of National Programmes" with reference to Article 12.1 of the Council Directive 2011/70/EURATOM

ii. Joint organization together with DG RTD and DG ENER of the EURADWASTE 2013 conference, summing up and making conclusions of the FP7 EURATOM waste programme,

iii. Establishing jointly with the European Academies Science Advisory Council (EASAC)) document with Guidance for Decision Makers on Waste Fuel Cycle Options from the view point of Waste Management

iv. Support to the IAEA in establishing guidance on, for example long-term safety of disposal of radioactive waste (GEOSAF), as well as participation in assessment of the Waste Technology work programme (International Radioactive Waste Technical Committee (WATEC))

Impact. The impact of these Deliverables is a progressive harmonization of the understanding of what is required in order to implement responsible and safe management of spent fuel and radio-active waste, in particular but not only in the European Union

3.3. Major Highlight(s)

Major highlights are summarized as:

- Unique analytical infrastructure is further developed, for example the Surface Science Lab-Station where several operators can simultaneously investigate a multitude of samples for their chemical surface structure on an atomistic scale, as well as the surface chemical and physical properties.
- Studies to extrapolate the potential evolution of spent fuel during extended storage using a combination of spent fuel and alpha-doped analogues identified only excess fuel swelling induced by helium accumulation as potential concern.
- Calibrated transversal impact tests on spent fuel rods have been performed on commercial LWR fuel with burnup in the range 20-70 GWd/tHM to address concern by the regulator about the release of fuel in case of rod mechanical failure during transportation. The results showed that under the conditions tested only the volume of fuel directly affected by the rod fracture is released, namely less than one single fuel pellet.
- The rim region of spent fuel pellets (namely, the High Burnup Structure), where a high concentration of fission products, plutonium and minor actinides occurs, shows strong resistance against water corrosion compared to other regions of the fuel.

- The instant release fraction of highly mobile species (e.g. Cs) measured experimentally corresponds only to a few % of their local inventory. The data clearly indicate that conservative assumptions (e.g. assuming an instant release fraction of 100%) are unjustified.
- The beneficial effect of hydrogen in a repository near field with respect to inhibition of spent fuel matrix dissolution has been characterized on spent fuels (UO2, MOX) and on alpha-doped analogues. This effect is now taken into account in the safety assessment for the geologic repository.
- Extent and relevance of alpha-radiolysis dissolution-enhancing effects have been characterized. A threshold for this effect (under the experimental conditions considered) has been identified and translated into spent fuel age. This provides an indication of the temporal extent during which radiolysis would be expected to play a role in determining the dissolution mode for spent fuel in a repository.
- The catalytically driven process of chemical reduction through the presence of hydrogen affecting spent fuel corrosion behaviour was associated to the presence of chemically active spent fuel material surfaces, including noble metal fission product precipitates. In particular, a new radiation driven photo-catalytic process has been identified.
- A Guide for the Member States in implementing the Council Directive 2011/70/EURATOM (the "Waste Directive") was published by European Nuclear Energy Forum (ENEF) where JRC-ITU plaid an important role throughout the drafting process.
- A Guide is developed for decision makers on the impact of different fuel cycle options on the associated radioactive waste management (published in 2014)[1]

Highly relevant topics for ongoing/future research projects have been identified and are now being implemented in HORIZON 2020 together with continuing activities. Among others, these include studies on conditioning and long term behaviour of damaged spent fuel, spent fuel rod response to mechanical solicitations corresponding to specific conditions expected during transportation or after storage, decommissioning applications of JRC know-how and developments

4. Further Information

4.1. Integration and Networking

Networking of the action is done by participation in competitive activities, which bring together the major European player in the field of the activity.

Furthermore the action is involved in collaborations with EU Member States' universities or organisations as well as international organisations.

[1] https://ec.europa.eu/jrc/en/news/new-long-term-nuclear-spent-fuel-management-report

4.2 List of Competitive Activities

30955	CARBOWASTE	DG RTD	IA
30956	RECOSY	DG RTD	IA
32234	FIRST-NUCLIDES	DG RTD	IA
30306	MOX SPENT FUEL CHARACT. PROGR.- FY 2006	CRIEPI	TPW
30584	(U,DY)O2 THERMAL PROPERTY MEASUREMENTS	BRUCE POWER LP*	TPW
30586	(ZR, GD, DY,Y) O2 THERMAL PROPERTIES	ATOMIC ENERGY OF CANADA LIMITED AEC	TPW
30640	EXP. UNTERSUCHUNGEN AN BRENNSTÄBEN	GNS GESELLSCHAFT FUR NUKLEAR-SERVIC	TPW
30884	MOX SPENT FUEL CHARACT. PROGRAM FY 2007	THE CENTRAL RESEARCH INSTITUTE OF E	TPW
31219	NDA DIRECT RESEARCH AGREEMENT 3300003154	UKAEA LIMITED*	TPW
31455	SURFACE SCIENCE INV.ON SPENT FUEL MODELS	SVENSK KARNBRANSLEHANTERING AB*	TPW
32672	LEACHING IRRADIATED AGR FUEL	NATIONAL NUCLEAR LABORATORY LTD*	TPW
33305	IGD-TP CONFERENCES IN MANCHESTER	NUCLEAR DECOMMISSIONING	TPW

4.3. Mobility and training of researchers

The action is involved in the training of young researchers (PhD students) as well as post-doctoral students. During the reporting period, 6 PhD students, 10 post-doctoral fellows have been part of the staff, and a series of Visiting Scientists were hosted including user access programme.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action *51201- ANFC*

Alternative Nuclear Fuel cycles

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0. Policy Area

Policy theme 5 – The EURATOM programme
Thematic area - TA5, Nuclear Safety and Security
Agenda no and title - 5.1 Nuclear waste management and environmental impact
Sub agenda and title - 5.1.2 Partitioning, Transmutation and Conditioning

1. Rationale of the action

The safe and responsible long-term management of toxic and highly radioactive wastes is an ethical obligation of each Member State to avoid any undue burden on future generations. Each Member State remains free to define its fuel cycle policy and at present mainly two different nuclear waste management strategies are followed. The strategy adopted by most countries is a direct disposal of the spent nuclear fuel, whereas in some other countries spent nuclear fuel is industrially reprocessed to recover and recycle fissile uranium and plutonium for a more efficient use of valuable energy resources. Regardless of the strategy chosen, the nuclear fuel cycle policy in Europe should rely on state-of-the-art science and technology to assess the safety of these options and support a scientifically sound nuclear waste management policy in each Member State.
The ANFC action deals mainly with an alternative strategy where the volume and the radiotoxicity of high-level waste should be significantly reduced, thus shortening the time scales needed for safe storage and associated risks. This fuel cycle strategy includes the recovery of long-lived minor actinides and their conversion into shorter-lived or stable ones by irradiation in dedicated reactors, so called Partitioning and Transmutation (P&T). The activities in this action span therefore over fuel material development and characterisation, irradiation programs and recovery and recycling schemes.
The strategy is also included in the target of the European Sustainable Nuclear Industrial Initiative (ESNII) established under the Sustainable Nuclear Energy technology Platform (SNETP). The aim is the deployment of Gen-IV fast neutron reactors with closed fuel cycles. The reference technology is the sodium cooled system with the ASTRID prototype in France, alternatives are the lead cooled systems with the pilot prototypes ALFRED in Romania and MYRRHA in Belgium and the gas cooled system with the demonstrator ALLEGRO developed in Czech Republic, Hungary and Slovakia and Poland. The common goal is to increase the sustainability through optimised U usage and a significant reduction of the hazard posed by radiotoxic waste within the realm of partitioning and transmutation.
The ANFC Action provides evidence-based scientific and technical support to EU nuclear waste management policies, independent of national and commercial interests. It plays an important role in the maturing of the European Research Area (ERA) by contributing through mobility and training, the further opening of its research infrastructures, its participation in joint programmes in research, knowledge transfer including open access to the JRC knowledge database

2. History and development of the action

The research in P&T cycles, i.e. recovery of long-lived minor actinides (or radionuclides) and the conversion into shorter-lived or stable ones by irradiation in dedicated reactors is progressing in the institute since decades. The basic motivation is the reduction of radiotoxicity and the volume of the nuclear waste. The ANFC action follows several previous P&T programs including a long series of irradiation experiments and investigations of various MA recycling schemes.

The research done within the ANFC action is carried out in close collaboration with European and international partners under the FP7 programme, including third party work based on bilateral collaboration agreements

The ANFC action establishes the characteristics and safety related properties of irradiation targets and fuel samples in order to provide reference data for advanced fuel safety assessments. ANFC had strong links to several European irradiation programs, such as EUROTRANS, FAIRFUELS and PELLGRIM, providing synthesis and characterisation of fuel materials before and after irradiation. Special focus was given to local structure experimental data for the fundamental understanding of fuel and material behaviour and their modelling for safety studies.

A consortium led by Thor Energy, Norway, including Westinghouse, Fortum NNL and JRC has been formed, to evaluate the performance of Th-MOX fuels in nuclear reactors. Two pins containing Th-MOX pellets supplied by JRC-ITU were included in an irradiation experiment in the Halden reactor.

Also the molten salt reactor concept, one of the reactor systems retained in the Gen IV initiative, was studied within ANFC. Contributions to the European EVOL program relative to the molten salt fuel composition are key elements to a definition of the design of a molten salt fast reactor prototype.

In the ANFC action, key processes were investigated in view of the development and assessment of alternative fuel cycles. Aqueous and pyrochemical processes for the separation and reduction of long-lived radionuclide inventories to shorten the time scales for safe storage and conditioning of high level nuclear waste were developed. The homogenous recycling of actinides was tested in the GANEX process as part of the European ACSEPT program. The experiment was jointly prepared by 6 partners of the consortium and the hot demonstration using genuine fast reactor fuel was demonstrated at the JRC-ITU. A similar approach of joint programming is also the key part of the presently running SACSESS programs.

The European programs also pyrochemical methods for the recovery of actinides are being studied. Here the long-lasting research collaboration program between CRIEPI (Japan) and JRC-ITU is included in the European program as complementary contributions. A central part is the METAPHIX program, a demonstration of minor actinide transmutation in a fast neutron spectrum based on metallic fuels. The fuels

fabricated in ITU were irradiated in the PHENIX reactor in Marcoule, France and successfully reprocessed in ITU in the frame of the FP7 program

Pyrochemical methods will also be evaluated for their potential as a safe and efficient way to condition damaged fuel such as the molten cores of the Fukushima Daichii reactors after the accident. Samples of the TMI reactor molten core available at ITU were used to demonstrate that molten salt electroreduction is a possible way to convert molten oxide material into metal allowing the grouped actinide recovery by molten salt electrorefining.

Another research program was devoted to safe storage of high level liquid waste in industrial reprocessing of spent nuclear fuel. In the frame of a TPW contract with CRIEPI/JNFL, Japan a research program was conducted using genuine fuels to provide data on the release of high level liquid waste constituents in case of a cooling failure during storage. The data are essential to obtain the operation license of the Rokkasho reprocessing plant in Japan.

3. Description of the action

3.1. Clients and stakeholders

Customers /users

Internal

- JRC – Joint Research Centre
- JRC KB – JRC Knowledge Base
- RTD – Research and Innovation

External

- AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION
- Academy of Sciences of the Czech Republic
- Budapest University of Technology and Economics
- Chalmers University of Technology
- Consejo Superior de Investigaciones Cientificas
- Czech Technical University in Prague
- Delft University of Technology
- IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE
- LAGRANGE
- Lancaster University
- NEXIA SOLUTIONS LIMITED
- Nuclear Research Institute Rez
- Nuclear Research and Consultancy Group
- POLITECNICO DI MILANO
- POLITECNICO DI TORINO
- RIJKSUNIVERSITEIT GRONINGEN
- Royal Institute of Technology

- SERCO LTD
- UNIVERSITA DEGLI STUDI DI PARMA
- UNIVERSITE LOUIS PASTEUR
- UNIVERSITE PIERRE ET MARIE CURIE
- UNIVERSITY OF LEEDS
- UNIVERSITY OF READING
- University of Edinburgh
- University of Liège
- University of Manchester
- University of Oxford
- University of Twente
- CU - Charles University Prague
- AREVA NP - AREVA NP Main Company
- CEA - Commissariat à l'Energie Atomique et aux Energies Alternatives
- CIEMAT - Centro de Investigaciones Energeticas Medioambientales Tecnológicas
- CNRS - Centre National de la Recherche Scientifique
- CRIEPI - Central Research Institute of Electric Power Industry
- EDF - Electricité de France
- ENEA - Agenzia Nazionale per le Nuove Tecnologie, L'energia e lo Sviluppo Economico Sostenibile
- ENEN - European Nuclear Engineering Network
- FZJ - Forschungszentrum Jülich
- HZDR - Helmholtz-Zentrum Dresden-Rossendorf e.V.
- KIT - Karlsruhe Institute of Technology
- NRG - Nuclear Research and consultancy Group, NRG
- PSI - Paul Scherrer Institute
- SCK-CEN - Belgian Nuclear Research Centre

Stakeholders

DG

- RTD – Research and Innovation

External

- Chalmers University of Technology
- NEXIA SOLUTIONS LIMITED
- Nuclear Research Institute Rez
- UNIVERSITY OF READING
- University of Twente
- CEA - Commissariat à l'Energie Atomique et aux Energies Alternatives
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- CNRS - Centre National de la Recherche Scientifique

- CRIEPI - Central Research Institute of Electric Power Industry
- ENEA - Agenzia Nazionale per le Nuove Tecnologie, L'energia e lo Sviluppo Economico Sostenibile
- FZJ - Forschungszentrum Jülich
- KIT - Karlsruhe Institute of Technology
- PSI - Paul Scherrer Institute
- SCK-CEN - Belgian Nuclear Research Centre

3.2 Major Objectives, deliverables and impacts

Objective 1

Establish the characteristics and safety related properties of irradiation targets and fuel samples through synthesis, participation in irradiation programmes and post irradiation examinations (PIE), in order to provide reference data for advanced fuel safety assessments

Deliverables:

High quality data set on safety related properties of irradiated as well as non-irradiated targets and fuel samples for waste minimisation through P&T

Impacts:

The investigation of safety related fuel properties is fundamental for the development of new improved fuel materials with better safety characteristics for transmutation.

Objective 2

Development of efficient and safe processes for the recovery of actinides (An) and long-lived radionuclides for the transmutation and resulting radiotoxicity reduction by aqueous and pyrochemical processes.

Deliverables

Several reports providing basic and applied scientific input to the partitioning programs in the European Research Area.

Impacts

The development work and the demonstration experiments in the JRC have led to the selection of improved processes for the recovery of actinides form nuclear fuels allowing for a higher efficiency and safety.

Objective 3

Characterisation of irradiated metallic fuels, their fuel cycle, safety aspect of tank waste, and pyrochemical methods as a safe and efficient way to condition damaged fuel. The objective is implemented in close collaboration with international partners in

and outside the EU within the frame of collaboration agreements and/or third party work contracts.

Deliverables

Reports on TPW research programs carried out for external customers on safety assessments of high level liquid waste storage in tanks and on conditioning of damaged fuel by molten salt electroreduction.

Impacts

The work carried out has supplied data, fundamental to assess accidental release scenarios involving reprocessing task waste. In addition the feasibility of a pyrochemical method to condition or treat damaged fuel has been proven.

3.3. Major Highlight(s)

- During FP7 several irradiation experiments were performed in Phenix and the HFR Petten using fuels prepared by the JRC ITU in the frame of the ANFC action to test the irradiation performance
- Phenix ceased operation in 2009, and before doing so the FUTURIX fuels (two pins of Mo based inert matrix fuel (IMF) reached the planned burnup. These pins will shortly arrive at the ITU hot cells for PIE, but no problems were encountered during their irradiation, as a part of the FAIRFUELS programme.
- The HFR Petten hosted the HELIOS irradiation experiment, containing four fuels prepared by the JRC-ITU. Two of these were based on (Zr,Y,Pu,Am)O2-x, one without Pu and one with Pu. The irradiation in the HFR was successful. PIE made at the JRC ITU hot cells showed that the Pu bearing fuel operated at higher (500°C) temperature, and showed the onset of the formation of a centre void, not unlike a MOX fuel. The other fuels irradiated in this test were Mo based CERMETS, which also showed an excellent in pile behaviour. This work was also performed as a part of the FAIRFUELS programme.
- With NRG at the helm, the project FAIRFUELS was granted. Therein the irradiation performance of (U,Pu,A)O2-x fuels are being tested in both pellet and sphere pac. This type of fuel is very close to MOX fuel, with only 3% of Am in the fuel, and is characteristic of homogeneous MA recycling in a fast reactor. The fuel was prepared at the JRC-ITU minor actinide laboratory (MA LAB) and was shipped to the HFR. The irradiation is ongoing and is due to be removed from the reactor in June 2015.
- Within the PELGRIMM project, coordinated by the CEA, JRC-ITU has manufactured fuels characteristic of heterogeneous minor actinide recycling. They are Pu free and are considered for the region near the blanket in the reactor core. Two fuels were produced. Both were of the chemical form (U,Am)O2-x, with an Am/(U+Am) ratio of 15%. Again the fuels were prepared in pellet and spherepac formats, and are waiting irradiation in the HFR Petten

- After Phenix ceased operation in 2009, minor actinides containing METAPHIX fuels of different burn-ups have been transported, received and subsequent post irradiation examination (PIE) at the JRC –ITU hot cell facilities has been carried out.
- A demonstration of a closed metallic fuel cycle with a grouped actinide recycling based on electrorefining on solid Al electrodes in molten salt eutectics was achieved
- Within the ACSEPT program, the first demonstration of a grouped actinide recovery, the so called GANEX process, for homogenous recycling in fast reactors was successfully demonstrated on dissolved fast reactor fuel in the JRC-ITU. The process was divided into two steps; the first handling bulk uranium and in the second step transuranium elements were selectively separated from the fission products.
- During FP7, the JRC reinforced its investigations on basic properties of minor actinides. This included Knudsen cell investigations to determine the thermodynamic properties of minor actinide bearing fuels, and the use of synchrotron radiation methods to determine local distortions and radiation damage in the structure of these materials. Furthermore, a word wide unique facility based on a magic angle spinning nuclear magnetic resonance spectrometer has been installed to extend the information obtained in these local structure studies.

4. Further Information

4.1. Integration and Networking

Integration with other JRC actions is strong due to the nature of the tasks of the action, in particular as cross-cutting with the back-end of the fuel cycle and the development of alternative and innovative fuels (in particular NWD2 and SANF/SNF). The action was also well integrated within the Indirection Actions programme of DG RTD and networking with large consortia. (see 4.2)

4.2 List of Competitive Activities

EUROTRANS (European research Programme for the transmutation of high level nuclear waste in an accelerator driven system) 2005 – 2010

The EUROTRANS project was devoted to transmutation of high-level waste by an accelerator driven system (ADS). The objective was the design and the feasibility assessment of an industrial prototype

PELLGRIM (pellets versus granulates: irradiation, manufacturing and modelling), 2012-2015

PELLGRIM is a 4 year project addressing Minor Actinide (MA) bearing fuel developments for Generation IV Fast Reactor Systems to support the strategic Research Agenda (SRA) of the European Sustainable Nuclear Energy – Technology Platform (SNE-TP)

LWR-DEPUTY (Light Water Reactor fuels for deep burning of Pu in Thermal systems) 2006 – 2011
LWR-Deputy was focused on experimental research on inert matrix novel fuels for deep burning of plutonium in existing nuclear power plants (NPP´s)

ACSEPT (Actinide separation for transmutation) 2008-2012
The collaborative project ACSEPT was devoted to develop chemical separation processes compatible with fuel fabrication techniques with a view to their future demonstration at pilot level.

SACSESS (Safety of actinide separation processes) 2013 – 2015
The SACSESS collaborative project will provide a structured framework to enhance the fuel cycle safety mainly associated to partitioning in P&T schemes. Safety studies are performed for each selected partitioning process and the data integrated to optimise flowsheets and optimise process operation conditions.

METAPHIX 1,2,3. 2006-2016
This shared cost collaborative project is devoted to the post irradiation examination (PIE) and behaviour of irradiated metallic An-Zr alloy fuel, the so called METAPHIX fuel.

CRIEPI –Pyro, Pyrometallurgical processes on transuranium elements, 2007 – 2016
This bilateral shared cost program aims at a development and demonstration of pyrometallurgical reprocessing of minor actinide containing metallic alloy fuels used in a double strata P&T fuel cycle.

CRIEPI-Dry out (Dry out experiments of high level waste), 2010 – 2014
This third party work project was related to safety studies of an accidental loss of coolant scenario for a HLLW tank waste facility. The main objective was to measure the fraction of radioactive material released through a complete dry out and subsequent volatilisation.

CRIEPI – Fuel dissolution, 2011 – 2012
In this third party project the dissolution of irradiated LWR fuels and characterisation of residues was studied

EVOL (Evaluation and Viability of Liquid Fuel Fast Reactor System), 2011-2013
This project was dealing with an innovative molten salt reactor concept, the MSFR (Molten Salt Fast Reactor) for MA burning as one of the Gen IV reactor system. The objective of this project was to propose a design given the best system configuration issued from physical, chemical and material studies.

4.3. Mobility and training of researchers

The action is involved in the training of young researchers (PhD students) as well as post-doctoral students. During the reporting period, 3 PhD students, 4 post-doctoral fellows, and 10 Visiting Scientists (mostly detached from national organisations and Japanese industry) have been part of the staff.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action *51301*

2007 – 2011
FAR (Fundamental and Applied Actinide Research)

2012 – 2013
FPANM (Fundamental Properties of Actinides and Nuclear Materials)

Action Leader: *(Eric Colineau, E06)*
Authorising Officer: *(Roberto Caciuffo, E06)*
Leading Institute: *(ITU)*

0. Policy Area

FP7 Policy Theme	5 The EURATOM programme
Agenda No & Title	5.1 Nuclear waste management and environmental impact
Sub-Agenda No & Title	5.1.3 Basic actinide research

1. Rationale of the Action:

As outlined in the Euratom Treaty, the development of research is crucial in ensuring safe use and innovation in the field of nuclear energy through fundamental understanding of nuclear material properties, technological progress, international cooperation, dissemination and enhancement of knowledge as well as training and education.

The G8 2009 Summit and the Council of the European Union emphasized the need to maintain a high level of training and education in the nuclear field to sustain, promote and disseminate highest safety and security standards at EU and international levels.

Raising Excellence in Science is a key priority to further develop the scientific basis to maintain the EU knowledge base and training and education at the forefront of nuclear safety and security. However, due to their high-radioactivity the study of actinide materials requires specific tools and facilities that are only available in a limited number of laboratories in Europe, hence only few academic and research organisations have the capabilities to work on these elements. Networking between existing European infrastructures in actinide sciences not only facilitates their efficient use by the European scientific community but also contributes to harmonisation and improvement of the nuclear education.

The JRC-Institute for Transuranium elements (ITU) is one of the few European centres dedicated to Actinide research with appropriate operating facilities. It plays a central role in the ERA by sharing its state-of-the-art facilities and complementary expertise with leading European universities and research organisations.

The aim of this Action is to provide the basic and more applied knowledge to underpin the understanding of nuclear materials and fuel processes (from production of energy to waste storage), and to stand as the “academic window” and reference centre of the JRC activities in the field, including knowledge dissemination through active contribution to the European Research Area (ERA).

2. History and development of the Action:

The action is a long standing activity of the JRC ITU, essentially oriented towards raising excellence in science. However, Periodic Action Review exercises have contributed to stimulate more policy relevance of the action while maintaining scientific excellence and continuous efforts are made. Mature basic research activities are transferred to other more applied actions (e.g. Nuclear Waste Disposal) with the aim to also reinforce the scientific output in those actions. In 2012, the FAR Action was renamed FPANM to reflect the fact that fundamental properties of actinides - necessary basis data for applied research, theoretical models and safety – are investigated, including on "nuclear materials" directly related to nuclear applications. The action became cross-cutting several units of the institutes, more particularly E.6 and E.3. It contributed also to producing and characterising samples and compounds to other actions both within the institute and the JRC.

3. Description of the Action

3.1. Clients and Stakeholders

Joint Research Centre (JRC), DG Research and Innovation (RTD), EU Member States, Enlargement and Integration countries, Academic institutions and organisations, Governmental and independent Research Organizations in the Member States and worldwide, Large Research Facilities, Scientific Community. A detailed list of organizations is given below:

Belgium: INPAC-Institute for Nanoscale Physics and Chemistry, Katholieke Univ. Leuven
Canada: Royal Military College and Queen's Univ., Kingston, Ontario
Czech Republic: Charles Univ. Prague; Institute of Physics, Academy of Sciences of the Czech Republic,ASCR, Prague
France: Commissariat à l'Energie Atomique CEA, Grenoble; CEA-Valduc, Is sur Tille; CEA Saclay; Institut Laue-Langevin ILL, Grenoble; Institute of Nuclear Physics/Univ. Paris XI, Orsay; European Synchrotron Radiation Facility ESRF, Grenoble; Centre National de la Recherche Scientifique CNRS, Palaiseau; Univ. Rennes, UMR CNRS 6226-Lab.
Chimie du Solide et Matériaux; CEMHTI-CNRS et Politech, Orléans; Ecole Supérieure de Physique et de Chimie Industrielles, Paris; Univ. Paris-Sud, Orsay
Germany: Hahn-Meitner-Institute, Berlin
Italy: Univ. Parma, Politecnico di Torino; Univ. Politecnica delle Marche, Ancona
Japan: Advanced Science Research Centre ACSR, Japan
Atomic Energy Agency JAEA, Ibaraki Prefecture (Tokai-mura);
SPRING 8, Japan Atomic Energy Agency, Hyogo
Netherlands: Utrecht Univ.
Poland: Institute of Low Temperatures and Structure Research PAS, Wroclaw
Romania: "Al.I. Cuza" Univ., Department of Inorganic and Analytical Chemistry, Iasi; Institute of Public Health, Radiation Hygiene Department, Timisoara
Sweden: Uppsala Univ.; Royal Institute of Technology KTH, Stockholm; VMO Konsult, Stockholm
Switzerland: Paul Scherrer Institute, Villingen
UK: Univ. College London; Rutherford-Appleton Laboratory, Oxfordshire; Univ. Manchester; Univ. Edinburgh; Clarendon Laboratory, Oxford Univ.; Diamond Light Source Ltd; Univ. Sheffield
USA: Los Alamos National Laboratory; Oak Ridge National Laboratory: Pacific Northwest National Laboratory; Harvard Univ., Cambridge

3.2. Major Objectives, deliverables and impacts

Objective 1: Chemistry of Actinides. Preparation of high quality samples, providing data and analytical assistance in the synthesis and characterisation of Actinide materials (metals, alloys and compounds) in support to internal and external research projects.

Deliverables:

- Metal Preparation. Pure metals of actinides are scarce and difficult to obtain. Beside the direct interest of better determining their properties, they are essential for

the fabrication of pure alloys and compounds. Development of a setup for distillation of amalgam and installation of furnace to obtain a good purity metal on gram scale completed the objective (production of ^{237}Np metal (1g) and ^{242}Pu (1.5g)).

- Samples preparation: Samples were prepared for solid state physics or thermodynamics measurements. Samples prepared were either used in-house, in particular through open user access programmes or sent to external organisations. During FP7 the demand of samples essentially focused on intermetallic compounds (e.g. $An_xT_yX_z$, An= Actinide, T: Transition metal, X= metalloid), Laves phases ($PuAl_2$…), U carbides ($UC_{(1-x)}$, $UC_{(1+x)}$), organometallics, … A large part of the work is also dedicated to the synthesis of single crystals of the materials prepared.

- Sample characterization: X-ray diffraction is the major technique used in solid state chemistry to characterise prepared samples, both on poly- or single crystals. Further development of the unit capacity in sample characterisation has been pursued (in particular single crystals and high-temperature diffraction devices) and adapted for working on highly radioactive materials. The service is also provided to characterisation of samples and materials from other units and institutes (more than 2,000 samples over the FP7 period).

- Sample encapsulation: The samples must be encapsulated for physical measurements in devices out of gloveboxes. Proper and dedicated encapsulation was performed for in-house measurements as well as for experiments outside ITU (large facilities, neutron reactors, synchrotrons, e.g. ILL; ESRF…)

- Organisation of training sessions (one day each) entitled "Phase and crystal structure analysis of polycrystalline X-ray diffraction data". The training sessions "hands-on" were organized to give the opportunity for the attendees to learn how to use various software available and practice on concrete examples the different steps to analyse polycrystalline X-ray/neutron diffraction patterns. Each session provided the opportunity for 10 attendees to practice exercises on computer.

Impacts

- A sustainable path to answer the community needs has been reached through the development and the preparation of ^{237}Np and ^{242}Pu pure metal by the amalgamation technique.

- The synthesis and characterisation capabilities of the unit make it a reference centre for the production of samples used in many experiments and projects. It is a key activity supporting the development of networking and collaboration with external organisations, both academic and more applied research.

- Large number of high impact journal publications (see list in annex) was achieved in collaboration with external research organisations demonstrating the complementarity of the JRC programme with external stakeholders and contributing to strengthen the scientific legitimacy of the institute.

Objective 2: Physics of Actinides. Determination of fundamental properties of actinide elements and compounds (relevant for their general understanding, safety assessments, codes development and modelling) to describe and predict their response to external conditions and their behaviour over the long-term by the

validation of theoretical models. The experimental data are combined with theoretical modelling to extend the basic understanding of the electronic structure of actinide compounds. .

Deliverables:

During FP7 the programme focused on bulk properties and electronic structure of alloys and compounds, transport and magnetic properties of 5f-unconventional superconducting compounds. It was extended to new field of research where 5f elements provide a unique playground for a better understanding of materials and challenging associated theoretical understandings, such as the Bonding Analysis of a Series of Singly Reduced Uranyl–Rare Earth 5f1-4fn Complexes, the investigation of strongly coupled binuclear uranium–oxo complexes and transuranic mononuclear complex. This was also complemented by theoretical studies of spectroscopic properties of Cm^{4+} and Am^{3+} as well as more applied materials such as uranium carbide.

Impacts

- The major impacts are obtained through high impact journals such as Nature, Physical Review Letters, Angewandte Chemie, etc. (see list in annex) to position the JRC as a reference knowledge centre in the physics and chemistry of transuranium elements and materials.

- The visibility obtained through this activity generates networking and collaborations (see publications list) as also illustrated by the invitation and participation in advisory boards and committees (10) of peer organisations: ESRF Committee on Hard Electronic Structure ; ILL - Scientific Council Subcommittee on magnetic structure ; PSI – SINQ science advisory committee ; International Iberian Nanotechnology Laboratory – International advisory committee ; Oak Ridge SNS proposal selection committee ; Hungarian Ministry of science and education, Evaluation Board of the International R&D large projects ; Italian Ministry of Research and University : Evaluation Board on recruitment of University Professors working abroad ; Italian Ministry of Research and University : Evaluation Board for Research project of national interest ; University of Coimbra (Portugal), Evaluation Board for temporary researchers ; Jury membership of the Olivier Kahn “International Award” ; Heinz Maier-Leibnitz Laboratory, Munich, exp. Selection Panels ; NIST (National Institute for Standard and Technology) exp. Selection panels ; CEA/DEN (Direction de l’Energie Nucléaire) Scientific Committee ; Le conseil scientifique du projet fédérateur NEEDS-Matériaux ; ACTINET-I3 / TALISMAN Steering Committee ; Actinide User Laboratory selection Panel ; Summer school Scientific Committee…

Objective 3: Surface science: Physics and chemistry of surface and interfaces: Investigation of the interaction of solids with the environment to determine and predict fuel behaviour during operation and waste corrosion. Research focuses on preparation of well-defined surface systems, from epitaxial thin films to nano-structures. Special emphasize is put on materials simulating nuclear fuel such as doped oxides, and actinide systems with peculiar electronic structure. Photoemission spectroscopy is used to study the chemical state of the surface and will be combined, with localized probes to unravel the reactivity of complex systems. Experiments are complemented by appropriate modelling activities.

Deliverables:

- Dataset on the electronic structure of Curium.

- Corrosion. Dataset on the influence of metal dopants on the corrosion mechanism and dissolution of UO_2 a) in normal conditions; b) under in-situ hydrogen high-pressure.

- Surface Interaction dataset on the surface interaction of PuO_2 with water

- Determination of the fundamental corrosion mechanisms and dissolution process of UO_2 (nuclear fuels) based systems for nuclear waste long term disposal behaviours

- Acquisition and installation of a HREELS (high resolution electron energy loss spectrometer) on the surface science lab station. Determine relationship between vibrational frequency of hydrogen and actinide oxide composition and doping, to unravel the mechanism of hydrogen activation on nuclear waste.

- Study of the ice overlayer interaction with NpO_2 and U-Pu MOX films to understand the surface reduction in these systems

- Preparation of transuranium metal films by in-situ thermoreduction/evaporation of actinide compounds (oxides), to open a fast and flexible road of preparing small amounts of actinide metals/compounds for in-situ surface science studies.

Impacts

- The major impacts remain through publications in high impact journals and positioning the JRC as a reference knowledge centre in the physics and chemistry of transuranium elements and materials in a more applied filed, in particular nuclear waste management and disposal.

- The fundamental and more applied studies delivered in this field contribute to the deeper understanding of processes and phenomena highly relevant for further modelisation and safety assessment of long term disposal of radioactive wastes.

Objective 4: Thermodynamics. Determination of high-temperature thermodynamic properties and phase diagrams of actinide materials. Provide "missing" assessed thermodynamic data of actinides in nuclear safety related materials. These data are fundamental to later assess the safety of such materials in nuclear power industry.

Deliverables:

- Thermodynamics of Molten salt: The molten salt reactor (MSR) is one of the six reactor concepts of the Generation IV initiative, an international collaboration to study the next generation nuclear power reactors. The fuel of the MSR is based on the dissolution of the fissile material (235U, 233U or 239Pu) in a matrix of a molten salt that must fulfil several requirements with respect to its physical properties. These requirements are very well satisfied by the various systems containing alkali metal and alkali earth fluorides. In this study binary fluoride systems have been thermodynamically assessed in order to predict the fuel properties in terms of the melting behaviour, the vapour pressure and the solubility of the actinides in the fuel matrix. In particular, the LiF-BeF2 binary system has been thermodynamically evaluated using the modified quasi chemical model for the excess Gibbs energy optimization.

- Actinide oxides. Dataset on the thermodynamic properties of actinide oxides (U, Pu, Np, Am): vapour pressure and vapour composition under vacuum and under

various atmospheres. Activity of Pu in MOX. Melting point and phase diagram studies of oxides and carbides.

- Determine and characterize the fundamental thermal properties and phase diagram of potential advanced and new generation nuclear power reactor nuclear fuels and related materials. These data are fundamental to later assess the safety of such materials in nuclear power industry.

- Dataset on the thermodynamic properties: vapour pressure of different actinides and actinide compounds in oxides; experimental work on the high temperature phase transitions at room and high pressure (continuation of the 2012 work) of Th, U, Np, Pu and (in a preliminary way) Am oxides, including new techniques such as UV pyrometry and high temperature cells. The results are integrated in broader phase diagram studies to be completed with the help of different methods of chemical analysis for an accurate sample characterization before and after the thermal cycles

- Studies of U, Np, Pu, Am oxides, U, Pu fluorides, experimental development and validation.

Impacts

- Beside publications in peer reviewed journals (see list in annex), the major impact is obtained through the contribution to reference database on thermodynamics properties of nuclear fuel-relevant materials. It provides set of data necessary and used by the Community which cannot be obtained elsewhere or complementary with MS national and international programmes.

Objective 5: Modelling. Analyse basic properties (formation energies of defects, atomic structure and lattice deformation around impurities, mixing enthalpy for solid solutions etc.) of nuclear fuels, by means of first-principle calculations, and compare them with experimental results (e.g. EXAFS results). Prepare and follow up bilateral agreements (e.g. Imperial College) for completing the atomic scale activities of ITU.

Deliverables:

- Study of the solid solutions by means of the first principles VASP code

In the course of the study of the solid solutions by means of the first principles VASP code, a number of supercells was defined to vary the composition in (U,Zr)N. Namely, the concentration of Zr varies from 12.5% to 75% and both cubic and tetragonal symmetries are supposed with two magnetic states: AFM and FM. It was observed that the magnetic effects appear to be important up to the concentrations of the order of 50%, and higher concentrations of Zr suggest no serious magnetic effects in the frame of conventional DFT calculations done up to now.

- Modelling of Nitrides. Study of the mixing energy and basic properties of U-Zr-Nitride

- Quantifying the contribution of the on-site correlation effect (U-term) in the DFT approximation for UO2, UN and (U ,Zr)N fuels. Estimate the formation and migration energies for defects in (U,Zr)N and the thermal properties (heat capacity) of UN and (U,Zr)N (one publication).

- Evaluation of accurate data for molecular actinide species using quantum chemical calculations incorporating electron correlation and relativistic effects. Multireference ab initio (CASPT2) calculations are performed as well as density functional theory in cases, where CASPT2 cannot handle larger molecules with numerous electrons and atomic orbitals, depending on available experimental data. The modelling is supported by new experimental data, obtained from matrix-isolation vibrational spectroscopy utilizing our Raman spectrometer as well as from cooperation with external groups in this field.

Impacts

- Models for the properties of nuclear fuel-relevant materials

Objective 6: Networking, user's access, workshops and conferences, training and education activities contribute to sustain and disseminate the knowledge and expertise, as well as to maintain the threshold level of research activity in actinide sciences in Europe. Opening the JRC-ITU's actinide research facilities to offer opportunities for researchers in European Universities and Institutes.

Deliverables:

- Reports. Financial and scientific reports for Actinet and Talisman

- Annual reports of the Actinide User Laboratory

- Delivery of 432 access days in Actinet-I3 (2010-2012) and 150 access days in Talisman (2013)

- Delivery of 619 operating days to users of the Actinide User Laboratory programme (2007-2013)

- Organisation of Actinide Summer Schools at ITU (2007, 2009, 2011, 2013)

- Contribution to the organization of international conferences: Plutonium future: the science (2008, 2012)[2], Journées des Actinides (2007, 2008, 2009, 2010, 2011, 2012, 2013), Actinides (2013)[3], Actinide symposium at the 2012 Materials Research Society Meeting in San Francisco, 2012 JRC-IAEC Collaboration symposium, 2012 REIMEI symposium, NuMat 2010, Euract-NMR 2013.

[2] **- Plutonium futures - The Science, 2008 and 2012 editions**

The "Plutonium Futures - The Science" series of conferences provides an international forum for the presentation and discussion of current research on the physical and chemical properties of plutonium and other actinide elements. Topics addressed range from the complexities of condensed matter physics in plutonium to practical issues such as trace detection of plutonium in the environment. The 2008 edition took place on July 7-11 2008 in Dijon (France), organised by ITU in collaboration with CEA (France) and AWE (UK). The same consortium organised the 2012 edition in Cambridge (15-20 July 2012) (UK).
The interest of the community on both events was reflected in the high attendance, with more than 300 participants from all over the world. Lively round-table discussions on global security and environment concerns completed the scientific programmes.

[3] **- Actinides 2013**

The Actinides 2013 conference, the world largest conference on actinide science, was organised on July 21-26, 2013 in Karlsruhe, jointly by JRC and KIT. The event provided a platform for discussion and information exchange for current research in the physics and chemistry of the actinide and the transactinide elements. Specific topics included fundamental materials science, chemistry, physics, environmental science, and application technologies.

- Karlsruhe Nuclide Chart: A digital version of the Karlsruhe Nuclide Chart was prepared in order to create a multipurpose information tool for nuclear data: a single data source is used for web portals, data editing and high-resolution hard-copy output. The 8th edition of the printed Karlsruhe Nuclide Chart was released, providing updated information for the fundamental nuclear properties of 3113 nuclides, including 154 new entries and 279 data corrections.

Impacts

- European researchers need effective and convenient access to the best research infrastructures in order to conduct research for the advancement of knowledge and technology. The JRC action contributes to bring together, integrate on European scale, and open up its key research infrastructures to all European researchers, from both academia and industry, ensuring a more optimal use and joint development.

- European Research Area / Mobility of researchers / Access to infrastructures: 58 users from 13 countries performed experiments at ITU.

3.3. Major Highlight(s)

- Strong-coupling d-wave superconductivity in $PuCoGa_5$ probed by point-contact spectroscopy

A century on from the discovery of superconductivity, a complete understanding of some of the mechanisms that lead to its manifestation is still missing. We have investigated one of the very few transuranium superconductor known so far, $PuCoGa_5$, a 5*f*-electron heavy-fermion superconductor with a record high critical temperature T_c=18.5 K, where the short-range, isotropic attraction provided by simple electron–phonon coupling does not appear as an adequate glue for electron pairing. Our results prove that the wave function of the paired electrons has a *d*-wave symmetry, with four lobes and nodes, and show that the pairing is likely to be mediated by spin fluctuations. Electronic structure calculations, which take into account the full structure of the *f*-orbital multiplets of Pu, provide a hint that valence instability is a possible origin of these fluctuations. This work has been published in **Physical Review Letters** 100, 076403 (2008) and in **Nature Communications** 3:786 doi: 10.1038/ncomms1785 (2012).

- **Possible mechanism of superconductivity in $PuCoGa_5$ probed by self-irradiation damage**

Measurements of the electrical resistivity of a polycrystalline $PuCoGa_5$ sample reveal significant modifications of the superconducting properties as a function of time, due to the increase of defects and impurities resulting from self-irradiation damage. More than four years of ageing were necessary to detect a deviation from linearity in the time dependence of the critical temperature. The observed behaviour is understood in the framework of the Eliashberg theory, confirming the *dirty d*-wave character which was already suggested by nuclear magnetic resonance. This work was part of the PhD thesis of F. Jutier and appeared in F. Jutier et al., **Physical Review B** 77, 024521 (2008).

- Uranium and manganese assembled in a wheel-shaped nanoscale single-molecule magnet with high spin-reversal barrier

Discrete molecular compounds that exhibit both magnetization hysteresis and slow magnetic relaxation below a characteristic 'blocking' temperature are known as single-molecule magnets. These are promising for applications including memory devices and quantum computing, but require higher spin-inversion barriers and hysteresis temperatures than currently achieved. After twenty years of research confined to the *d*- block transition metals, scientists are moving to the *f*-block to generate these properties. We have prepared, by cation-promoted self-assembly, a large 5*f*–3*d* $U_{12}Mn_6$ cluster that adopts a wheel topology and exhibits single-molecule magnet behaviour. This uranium-based molecular wheel shows an open magnetic hysteresis loop at low temperature, with a non-zero coercive field (below 4 K) which suggests that uranium might indeed provide a route to magnetic storage devices. This molecule also represents an interesting model for actinide nanoparticles occurring in the environment and in spent fuel separation cycles. This work has been published in **Nature Chemistry** 4, 1011 (2012).

- $[An(H_2O)_9](CF_3SO_3)_3$ (An=U–Cm, Cf): Exploring Their Stability, Structural Chemistry, and Magnetic Behaviour by Experiment and Theory

We have reported a general and straightforward synthesis scheme for high-yield preparation of single-crystals of the oxidation-sensitive compounds 1(U-Pu), while a micro-synthesis approach was used for 1(Cf) owing to the scarcity and hard gamma emission of ^{249}Cf. These compounds, in particular 1(U), may serve as alternative precursors to the well-established $UI_3(thf)_4$ and the recently introduced UI3 and $U(CF_3SO_3)_3$. In addition, we find that for similar An^{3+}/Ln^{3+} ionic radii the $[An(H_2O)_9]^{3+}$ and $[Ln(H_2O)_9]^{3+}$ cation structures in 1(M) are almost identical. This reflects the electrostatic nature of the An/Ln-O bonds and thus suggests that the local structure of the hydrated ions in solution may also be similar. Finally, the magnetic susceptibilities of 1(U-Am) may be fully reproduced by ligand-field calculations, from which we can derive the 5f electronic level structures. This work has been published in **Angewandte Chemie Int. Ed.** 49, 6229 (2010).

- Order parameter of high rank in NpO_2

The first measurements in 1953 of the low-temperature specific heat on NpO_2 showed a clear phase transition at 25 K. Half a century later this phase transition is still of major interest because intensive research has shown that it involves the ordering of high-order magnetic multipoles. Such higher-order multipole densities appear in research areas as different as studies of nuclei deformations, molecular interactions, and phase transitions. They have been invoked to explain many unusual phenomena, but their experimental identification is always complex. Despite its exotic nature, the experimental situation in NpO_2 is now one of the clearest examples of this unusual ordering and the latest neutron experiments have added crucial experimental evidence to this long-running saga. Consistent with the theoretical predictions, the experiment gives strong evidence that the primary order parameter is of rank-5 – the triakontadipole. Although some details remain to be resolved, the neutron experiments and accompanying theory have played a key role in an extraordinary story extending over half a century; but still at the forefront of our understanding of phase transitions in condensed matter. This work has been published in, **Physical Review B** 78, 104425 (2008).

- Unconventional properties of the $NpPd_5Al_2$ superconductor

$NpPd_5Al_2$ crystallises in the $ZrNi_2Al_5$ structure type presenting a strong anisotropy. $NpPd_5Al_2$ (T_c ~ 5 K) is the first neptunium based superconductor to be reported and joined the two only other transuranium-based superconductors $PuCoGa_5$ (T_c ~ 18 K) and $PuRhGa_5$ (T_c ~ 9 K). These systems present bulk superconductivity arising from the *5f* electrons and display enhanced characteristics (T_c. J_c, H_{c2}) one order of magnitude higher than in other *f*-systems (Ce- or U- based heavy fermions). Crystals of $NpPd_5Al_2$ have been produced and basic physical properties (magnetism, electronic transport, Mössbauer spectroscopy and thermodynamic) have been examined in magnetic fields up to 14 T and at temperatures down to below 1 K. Comparison with cerium and uranium based Heavy Fermions Superconductors makes $NpPd_5Al_2$ a good candidate to search for an FFLO (Fulde-Ferrell-Larkin-Ovchinnikov) state at low temperature and high magnetic field. Other $AnPd_5Al_2$ compounds with the same crystallographic structure (An=Th, U, Pu, Am) have also been produced and studied at ITU. This work appeared in, **Physical Review B** 77, 212502 (2008) and **Physical Review B** 77, 092405 (2008).

- Compressibility of Californium metal:

Californium metal has been studied under pressure using diamond-anvil cells (DAC) and synchrotron radiation in a continuation of our studies into the structural behaviour of the actinide metals with pressure. The experiments which were performed in collaboration with Oak Ridge National Laboratory (ORNL) have shown that up to 35 GPa a mixture of 2 phases co-exist, namely Cf I (space group, *P63/mmc*) and Cf II (space group, *Fm3m*). Four series of experiments were performed at room temperature at the European Synchrotron Radiation Facility (ESRF). Because of the highly radioactive nature of ^{249}californium, only samples of 1 microgram or less per pressure cell were allowed at the synchrotron beam line which presented a particularly difficult technical challenge compared to other actinides previously studied.

The compressibility for Cf was obtained by fitting the Birch - Murnaghan and Vinet equations of state to the low pressure phases (regions of localized *f* electrons) to obtain the bulk modulus B_0 and its pressure derivative B'_0. The theoretical bulk modulus was calculated to be 37.4 GPa, in excellent agreement with the experimental results. These californium moduli are in line with values for the pure Am-Cf metals, which range from 25 to 43 GPa but considerably smaller than the moduli of the Th-Pu metals, which have additional bonding from their itinerant *f* electrons and are less compressible. This work has been published in **Physical Review B** 87, 214111 (2013).

- Triclinic–Cubic Phase Transition and Negative Expansion in the Actinide IV (Th, U, Np, Pu) Diphosphates

The AnP_2O_7 diphosphates (*An* = Th, U, Np, Pu) have been synthesized by various routes depending on the stability of the An^{IV} cation and its suitability for the unusual octahedral environment. Although they adopt at high temperature the same cubic archetypal cell as the other known MP_2O_7 diphosphates, they differ by a very faint triclinic distortion at room temperature that results from an ordering of the P_2O_7 units, as shown using high-resolution synchrotron diffraction for UP_2O_7. The uncommon triclinic–cubic phase transition is first order, and its temperature is very sensitive to the ionic radius of An^{IV}. The conflicting effects which control the thermal variations of the P–O–P angle are responsible for a strong expansion of the cell followed by a

contraction at higher temperature. This inversion of expansion occurs at a temperature significantly higher than the phase transition, at variance with the parent compounds with smaller M^{IV} cations in which the two phenomena coincide. As shown by various approaches, the P–O_b–P linkage remains bent in the cubic form. This work has been published in **Inorganic Chemistry** 51, 4314 (2012).

- Reassessing the melting temperature of PuO_2

The actinide oxides are currently the predominant fuel type of nuclear reactors. The melting behaviour is a fundamental property of a material, closely related to its structure and thermodynamic stability, and has therefore been a crucial subject of research for several decades. The melting point is also an important engineering parameter, as it defines the operational limits of a material in its application environment. This point becomes critical in nuclear engineering where the thermo-mechanical stability of a nuclear fuel element is a key factor determining fuel performance and safety. However, experimental difficulties stemming from the extreme temperatures, complex pressure-temperature-composition relations, and the high radioactivity make the study of melting of refractory actinide compounds particularly challenging. We have used a novel experimental approach, yielding new data and allowing a re-assessment of the PuO_2 melting temperature to a value of (3017 ± 28) K, i.e. significantly above previously reported estimates. This work has been published in **Materials Today** 13, 52 (2010).

- Actinide User Laboratory:

The “Actinide User Laboratory” programme provides access to ITU facilities to scientists from the European Union that does not have at their home institutions the necessary infrastructure to handle actinide materials. This programme has been partly (2006-2011) financed by the Actuslab-2 contract (RITA-CT-2006-026176) and partly by JRC (2013). The Actinide User Laboratory opens up important new opportunities for researchers in European Universities and research Institutes. Thanks to its truly unique character in Europe and access opportunities, it enables University researchers and their students to carry out research in the strategically important scientific field of basic actinide research to which they would have NO access without such opportunity. Through this Transnational Access programme, the actinide elements, all highly radioactive and chemically toxic but exhibiting great diversity in both their physical and chemical properties, become less “untouchable” to the European scientific community. This contributes significantly to the general increase of the awareness and expertise in the field, and is of particular interest to New Member States. In 7 years, 9 calls for proposals have been launched and 88 proposals have been received. 619 operating days have been delivered to 58 Users from 13 countries on 48 projects. 67 publications have resulted from this work.

4. Further Information

4.1. Integration and Networking

The action collaborated with DG-RTD through the “Actinide User Laboratory” programme (see section 4.2), participated to the “Actinet” and Talisman networks of excellence, had collaboration agreements with the CEA (France), JAEA (Japan) and IAEC-NRCN (Israel) and had many other scientific collaborations (see detailed list in section 3.1).

The FAR/FPANM action collaborated with other actions, in particular through the Characterization of samples by X-Ray diffraction (52301-SANF, 51102-NWD, 51201-ANFC) relevant for the Safety of Advanced Nuclear Fuels, Nuclear Waste Disposal and Alternative Nuclear Fuel Cycles that contribute to the implementation of EU

policy. This structural characterization is necessary to the studies involving these samples. The organization of conferences ("Journées des Actinides", where some scientists are supported by the "Enlargement and Integration" budget) and the Actinide User Laboratory (some projects conducted in other actions, e.g. AUL-103, 51502-AIT, AUL-114, 51102-NWD) also represents collaborations with other actions.

4.2 List of Competitive Activities

- "Actinide User Laboratory" - Actuslab-2 / Transnational Access / DG-RTD, contract (RITA-CT-2006-026176).

Access to Actinide Research Infrastructures for the scientific community:

- Actinet (ftp://ftp.cordis.europa.eu/pub/fp7/fission/docs/euradwaste08/papers/paper-18-actinet-a-network-of-excellence-in-th-fanghanel_en.pdf)
- Talisman (http://www.talisman-project.eu/)

4.3. Mobility and training of researchers

In addition to a large number of external scientists spent some time at the infrastructure in the frame of the Actinide User Laboratory (58), Actinet-I3 (17) and Talisman (5), more than 30 young researchers (PhD and post-docs) were provided JRC grant fellowships and hosted within the action.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action *51401 ND-Stds*

Basic research in nuclear physics and nuclear data standards

Action Leader: *Franz-Josef Hambsch, SN3S Unit*

Authorising Officer: *W. Mondelaers, SN3S Unit*

Leading Institute: *Institute for Reference Materials and Measurements*

0. Policy Area

Policy Theme: 5. EURATOM programme

Agenda N° & Title: 5.1 Nuclear waste management and environmental impact

Sub-agenda N° & Title: 5.1.4 Nuclear Data

Policy documents:

COM 2010 618 COUNCIL DIRECTIVE on the management of spent fuel and radioactive waste

COM 2011 311: A strategic vision for European standards: Moving forward to enhance and accelerate the sustainable growth of the European economy by 2020

COM 2011 563: 1st Situation Report on Education and Training in the Nuclear Energy Field in the EU

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0563:FIN:EN:PDF

COM 2011 593: COUNCIL DIRECTIVE laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation

SEC 2007 12: AN ENERGY POLICY FOR EUROPE

1. Rationale of the Action:

What we stand for:

The action “Basic research in nuclear physics and nuclear data standards” provides accurate neutron data measured at its unique facilities in support of safe operation of nuclear reactors and the safe handling of nuclear waste. With the focus on the Horizon 2020 Smart and Sustainable Growth flagships this action provides key experimental data for new and improved evaluated nuclear data files and for the nuclear reaction standards database. The focus on safety and security of nuclear energy in the Europe 2020 agenda determines the direction of research. Smart Growth is supported by nuclear data research, training and education and Sustainable Growth by providing data for validated nuclear data libraries like the Joint Evaluated Fission and Fusion library – JEFF. The action also contributes to the European Research Area (ERA) by providing high accuracy nuclear data in support of the priorities of international organisations that underpin innovation.

What we deliver

The Sustainable Nuclear Energy Technology Platform (SNETP) underlines the importance of the research dimension of the nuclear sector, the need to maintain high levels of safety, the importance of retaining competences and know-how and the increasingly competitive nature of this global industry.

In the Strategic Research Agenda (SRA) of the SNETP it is mentioned that the availability of accurate nuclear data is the basis for precise reactor calculations both for current and new generation reactors. Additional experimental measurements and their detailed analysis and interpretation are required in a broad range of neutron energies and materials. This is particularly true for fuels containing minor actinides for their transmutation in fast spectra.

Hence, the action will provide key experimental data for new and improved evaluated nuclear data files and for the nuclear reaction standards database, which is used in all validated nuclear data libraries, e.g. Joint Evaluated Fission and Fusion (JEFF) file and Evaluated Nuclear Data File (ENDF/B). In this way the action supports the

member States of the EC in their nuclear programs. Neutron data standards are basic data sets needed for experiments related to the assessment of reactor safety and nuclear waste minimisation.

In addition information about neutron and gamma ray multiplicities will be provided in response to requests in the High Priority Request List of the OECD/NEA.

These are essential for estimates of nuclear criticality, decay heat production, activities and dose rates, all important quantities of immediate concern to safety and security of nuclear energy.

Our stakeholders

To strengthen its role as a reference nuclear data provider, the action's activities emphasise collaboration with stakeholders in Europe and world-wide. Priorities and specific objectives for new measurements in the field of Community policy derive from co-operation organised by the NEA databank of the Organization for Economic Cooperation and Development (OECD) and by the Nuclear Data Section of the International Atomic Energy Agency (IAEA) and from bilateral collaborations with stakeholders - research institutes and universities in Europe and worldwide -, mostly formalized through collaboration agreements.

2. History and development of the Action:

This project is devoted to the study of neutron data standards and reaction theory and produces and improves neutron data for applications. The work programme follows the most urgent demands in close co-operation with international committees. Activities include support for the safety of current day reactors and spent fuel, nuclear waste management, and issues related to sustainability. To ensure customer orientation each project is embedded in collaborations with parties outside the JRC. JRC-IRMM represents the European Commission in the Nuclear Science Committee of the OECD Nuclear Energy Agency (NEA) and the Scientific Coordination Group of the Joint Evaluated Fission and Fusion file project (JEFF) of the NEA databank, as well as the OECD Working Party on Evaluation Co-operation (WPEC). JRC-IRMM is also involved in several IAEA Coordinated Research Projects (CRP) as well as in projects funded by the International Science and Technology Centre (ISTC).

The action is also ready to provide policy advice, as needed, in fields compatible with the competences of its staff.

Key activities of the action are

1. experimental and theoretical work for the understanding of the nuclear fission process in particular on fission yields and decay data

2. measurements of neutron data standards

3. development of improved measurement techniques using state-of-the-art technology

4. participate and contribute to internal and external international projects and network to support EC member states and associated states

These research activities are an excellent opportunity for training of young nuclear scientists in close collaboration with European Universities. Post-doctoral fellows and visiting scientists from the major neutron data laboratories in the world, ensure a continuous information exchange on latest developments.

Via a cooperation of JRC-IRMM with JRC-IE (action 52303: CAPTURE) nuclear data not distributed via the NEA data bank will be made available to the international community.

The specialised and unique facilities and its expertise enable JRC-IRMM to provide cross-section data over the complete neutron energy range from a few meV up to about 20 MeV. JRC-IRMM invests continuously in the upgrade of its accelerators and the laboratory equipment to keep them up-to-date. New developments in the use of digital data acquisition systems and signal processing are carried out as part of larger collaborations and will be used in measuring complex reactions needed for present day reactor and spent fuel safety and waste minimization.

There is a very close link to Action 51402 (ND-MINWASTE). Important benefits are drawn from action 53102 (METRO) that is responsible for the production and characterisation of the samples used for the measurements of the action. A close cooperation with JRC Action 51603 (RADMET) gives access to measurement capabilities in the radionuclide metrology laboratory of IRMM and the HADES underground laboratory for very-low-background measurements. The action is also participating in the FP7 competitive activities (see ch. 4.2).

3. Description of the Action

3.1. Clients and Stakeholders

Information as in the existing PAR files

Customer/users (outside the European Commission):

- IAEA
- OECD
- National Institute of Standards and Technology (NIST), USA
- Los Alamos National Laboratory (LANL), USA
- Department of Energy (DOE), USA
- Commissariat à l'Energie Atomique (CEA), France
- Centre National de la Recherche Scientifique (CNRS), France
- Joint Institute of Nuclear and Energy Research, Minsk, Belorussia
- Chalmers University of Technology
- PTB - Physikalisch-Technische Bundesanstalt
- HZDR - Helmholtz-Zentrum Dresden-Rossendorf e.V.
- IAEC - Israel Atomic Energy Commission
- IFIN-HH - Horia Hulubei National Institute of Physics and Nuclear Engineering
- Member State Universities

Customer DGs (inside the European Commission):

- Energy and Transport
- Research and Innovation

3.2. Major Objectives, deliverables and impacts

Objective 1: To conduct pre-normative research that enhances the knowledge base needed for improved safety modelling of nuclear reactors

Deliverables: Supply high quality nuclear data on request to OECD countries, international organisations and Member States

Impacts: Many datasets have been delivered to Member State laboratories and universities, international organisations and OECD countries. The requests have been registered in ARES and used in the PAR exercises. The high quality nuclear data of JRC have led to improved modelling of the fission process and nuclear reaction calculations documented in several publications with common authorship (see list of publications).

Objective 2: Determine high quality nuclear data requested with high priority by OECD and/or IAEA and/or Member states laboratories for nuclear criticality calculations

Deliverables: Supply high quality nuclear data for nuclear criticality calculations

Impacts: Improved nuclear criticality calculations: better description of prompt fission neutron spectra (PFNS) allowing for a more accurate neutron balance calculation in reactor applications. Better experimental data on neutron spectra and multiplicities are needed to improve the description of prompt fission neutron spectra (PFNS) allowing for a more accurate neutron balance calculation in reactor applications. Presently the IAEA has a Coordinated Research Project on Prompt Fission Neutron Spectra of Actinides; the summary report of the last meeting in October 2013 is in preparation. The objective is a better description of prompt fission neutron spectra (PFNS) allowing for a more accurate neutron balance calculation in reactor applications in 2014.

Objective 3: Determine high quality nuclear data requested with high priority by OECD and/or IAEA for nuclear decay heat calculations

Deliverables: Supply high quality nuclear data for modelling of the nuclear fission process

Impacts: Promote standardisation and harmonisation at European & international level Improving national security and nuclear security (as a result of the Lanthanide-halide gamma-ray detector characterisation). This task has high significance on improving national security and nuclear security through verification of better tools for non-proliferation, treaty verification, emergency response and anti-terrorism programs. This work will improve detection techniques, which are highly relevant for decommissioning i.e. bulk monitoring (for γ and neutron emitters). This work can support the research activities in the field of nuclear decommissioning by creating the means to promote and endorse harmonisation and traceability of

radioactivity measurements and radiological characterisation techniques used in nuclear decommissioning and to perform advanced research to strengthen the science-base of standardisation in nuclear decommissioning and contribute to further technological developments

Objective 4: Determine high quality nuclear data requested with high priority by OECD and/or IAEA for modelling of the nuclear fission process

Deliverables: Supply high quality nuclear data for modelling of the nuclear fission process

Impacts: Nuclear Waste Management, fuel burnup, criticality and decay heat: improve knowledge about waste handling and geological storage. Fission yields play an essential role in the determination of actinide burn-up in nuclear reactors. The present evaluations (JEFF, ENDF, JENDL ...) however do not contain any dependence of fission yield as a function of incident neutron energy. Here our data play a crucial role. Furthermore it has been found that fission yields are off by up to 20% depending on the correction method for prompt neutron multiplicities. This will have a strong impact on new evaluations as all data are based on average multiplicity corrections. To tackle the issues on fission yields the NEA Working Party on Evaluation Cooperation has a subgroup on "Improved fission product yield evaluation methodologies". Also the OECD/NEA has a working group dealing with Decay Data and Fission Yields for the JEFF evaluation. This work will improve knowledge about waste handling and geological storage and enable Member States to improve long term security of geological storage places.

Objective 5: To provide high quality neutron data for the IAEA standards file for nuclear safety

Deliverables: Supply high quality nuclear data on request to OECD countries, international organisations and Member States

Impacts: Improvement of the nuclear data standards file of the IAEA. Promote standardisation and harmonisation at European & international level. ^{10}B and ^{7}Li reactions have been identified as of need for improved and high resolution measurements. Those data are taken up by the IAEA Data Development Project to allow new experimental data and improved evaluation procedures to be available for future evaluations of the standards file. The IAEA has established this Data Development Project to include new experimental data in a more frequent evaluation of the IAEA standards file, the only world-wide standards file for nuclear data and used in all evaluation projects.

Objective 6: To develop improved state-of-the-art techniques needed for standardisation and harmonisation of neutron measurements

Deliverables: To improve measurement techniques using state-of-the-art digital technology

Impacts: digital technology applications have revolutionised nuclear measurement techniques. The action has been at the forefront of its application to

measurement challenges based on requests from the high priority request list of the OECD/NEA.

Objective 7: To foster knowledge management education and training

Deliverables: To deliver dedicated nuclear training and education on measurement standards for European policies

Impacts: In total 3 Master, 4 PhD, 13 Post-Doctoral students have been trained during the present reporting period in the action (see ch 4.3). In addition 5 visiting scientists supported the work of the action in the reporting period. This valuably contributes to the next generation expertise in nuclear science and technology. Four PhD theses have been finalised in the reporting period and a large amount of the publications were produced in collaboration both with the fellows and external collaborators from Member State institutions.

3.3. Major Highlight(s)

- $^{10}B(n,a)^{7}Li$ branching ratio, angular distributions and cross sections as important contribution to the IAEA Coordinated Research Project “Improvement of the Standard Cross Sections for Light Elements”, which ended up in a new evaluation of the standard cross sections for the Evaluated Nuclear Data File Version VII (ENDF/B-VII). Since then the IAEA has initiated a Data Development Project on neutron data standards.
- Prompt fission neutron spectrum from $^{235}U(n,f)$ at thermal incident neutron energy as an important contribution to the IAEA Coordinated Research Project " Prompt Fission Neutron Spectra of Actinides" (2010-2014). The JRC results are considered as reference data for $^{235}U(n,f)$ for benchmarking other data-sets.
- Identification of a shape isomer in ^{235}U compound system (Exploratory research and NUDAME). This lead to the first identification of a fission shape isomer in an odd-mass uranium isotope with determination of its half-live, important to improve nuclear barrier parameters. Published in Physical Review Letters.
- Scientific and technical support to Member State institution (CNRS, IPN Orsay): development of a unique directional fast-neutron beam with high intensity (LICORNE), letter of appreciation and request for further support (IPN Director F. Azaies, 07-2012)
- Measurement of prompt □-ray emission from $^{252}C(SF)$ and $^{235}U(n,f)$ with unprecedented accuracy due to the use of novel lanthanide-halide detectors. Experiments were performed based on request from the High Priority Request List of the OECD/Nuclear Energy Agency. Data are important ingredients to benchmark nuclear models. So far the under-prediction of □-heating by 10 - 28% could not be confirmed.
- Analysis of high quality fission fragment yield data for $^{234}U(n,f)$ measured at JRC-IRMM (PhD thesis of A. Al-Adili) assuming different neutron multiplicity dependencies heavy fragments revealed strong (20-30% impact on fission yield data. Data are an important ingredient for theoretical modelling and have

triggered the development of a neutron detector array for prompt neutron multiplicity measurements and strong collaborations with Uppsala University.

4. Further Information

4.1. Integration and Networking

Integration with other JRC actions is limited due to the nature of the tasks of the action. The only action which is very closely related to action 51401 is action 51402 ND MINWASTE. Here the integration is through context, customers and stakeholders, staff and the use of facilities. Important benefits are drawn from action 53102 METRO that is responsible for the production and characterization of the samples used for the measurements of the action. Finally, for knowledge management close links are established with the action 52303 CAPTURE coordinated by JRC-Petten.

Networking of the action is done by participation in competitive activities, which bring together the major European player in the field of the activity.

Furthermore the action is involved in collaborations with EU Member States' universities or organisations as well as international organisations. The action also plays a prominent role in participation in Coordinated Research Projects (CRP) of the IAEA in Vienna.

The action has frequent contacts with the US Department of Energy under the umbrella of the EURATOM-DOE collaboration agreement.

Collaboration agreements also exist with CEA and CNRS.

In the reporting period the action also organised 4 workshops within the Enlargement and Integration activities of the JRC. Each of the workshops (except one) was held in a then new member state (Romania) or candidate country (Serbia). They attracted on average 35 participants of which many PhD and Post-Doctoral students. Proceedings of each of the workshops have been published as a JRC Scientific Technical Report or in Physics Procedia.

4.2 List of Competitive Activities

European Facilities for Nuclear Data Measurements (EFNUDAT), 2007-2010

The EFNUDAT project aims at networking experimental facilities in Europe for nuclear data measurements providing a platform for better co-operation. The objective is to provide adequate trans-national access to the infrastructures and to co-ordinate joint research projects and S-T developments in support to other projects in the NUWASTE-2 programme.

European Facilities for innovative reactor and transmutation neutron data (EUFRAT), 2009-2013

A follow up of the NUDAME competitive activity, EUFRAT provides a four year scheme to facilitate transnational access to users of the JRC neutron measurement

facilities. Several groups of external users were supported by staff involved in the action.

European research Programme for the transmutation of high level nuclear waste in an accelerator driven system (EUROTRANS), 2005-2010

The EUROTRANS project is devoted to transmutation of high-level waste, focusing on transmutation in an Accelerator Driven System (ADS). The objective is the design and the feasibility assessment of an industrial ADS prototype dedicated to transmutation. The work is carried out by a consortium of 29 partners from 14 countries.

European Research Infrastructures for Nuclear Data Applications (ERINDA), 2009-2012

The ERINDA project aims for a coordination of European efforts to exploit up-to-date neutron beam technology for novel research on advanced concepts for nuclear fission reactors and the transmutation of radioactive waste. The ERINDA consortium groups 13 partners equipped with nuclear data research infrastructures. The proposal unifies facility management, research community and stakeholders. The aim of ERINDA is to integrate all infrastructure-related aspects of nuclear data measurements and to provide access for external user to the participating facilities.

Accurate Nuclear Data for Nuclear Energy Sustainability (ANDES), 2010-2013

The ANDES project intends to address the nuclear data needs associated to the new reactors and new fuel cycles supported by SNETP, in its SRA and in the ESNII proposal, taking into account the priority lists for nuclear data from NEA/OECD. New nuclear data measurements, dedicated benchmarks, based on integral experiments, and improved evaluation and modelling specifically oriented are included in ANDES to obtain high precision nuclear data for the major actinides present in advanced reactor fuels, reduce uncertainties for new isotopes in closed cycles with waste minimization and achieve a better assessment of uncertainties and correlations in their evaluation. The ANDES consortium groups 20 partners from 15 countries.

4.3. Mobility and training of researchers

The action is involved in the training of young researchers (PhD students) as well as post-doctoral students. During the reporting period, 4 PhD students, 13 post-doctoral fellows, and 5 Visiting Scientists have been part of the staff.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2013

Action 51402 *ND MINWASTE*

Nuclear data for radioactive waste management and safety of new reactor developments

Action Leader: *Arjan Plompen, Standards for Nuclear Safety, Security and Safeguards Unit*

Authorising Officer: *Wim Mondelaers, Standards for Nuclear Safety, Security and Safeguards Unit*

Leading Institute: *Institute for Reference Materials and Measurements*

0. Policy Area

Policy theme 5 – The EURATOM programme

Agenda 5.1 – Nuclear waste management and environmental impact

Sub-agenda N° & Title: 5.1.4 Nuclear data

1. Rationale of the Action:

This action fulfils the requirement of "neutron absorption" measurements of the JRC in the EURATOM Treaty in the context of current concerns: nuclear waste management, environmental impact and nuclear safety (see also the council decision on the EURATOM specific programme for the JRC in FP7 and its 2012-2013 extension). The action develops and applies the neutron and nuclear physics competences of interest to current developments in the nuclear field in Europe and organizes and involves itself with exchange of information and training and education efforts at Member States and International level, all in accordance with the Treaty. The action offers support to Member State organisations and universities through making its neutron measurement facilities available for their use through bilateral agreements and DG-RTD supported transnational access schemes (NUDAME, EUFRAT). In all its projects the action aims at addressing identified priorities in its field of competence which directly impact safety aspects of nuclear waste minimisation through recycling and transmutation of high level waste and of developments aiming at a sustainable nuclear energy supply. The cross-cutting nature of its activities make the action of relevance to Generation-II, -III and –IV safety studies. The action's impact is augmented and the results of its work are directly communicated and transferred to its stakeholders through co-operation within the EU in bi/multilateral and competitive projects and at international level through bilateral projects and co-operation on nuclear data organised by the OECD Nuclear Energy Agency and the International Atomic Energy Agency. Since Fukushima the action actively supports Japanese scientists of JAEA in developing experimental methods for characterisation of melted fuel in the decommissioning of the damaged Daichii plants through an experimental programme at its GELINA neutron source.

The neutron physics laboratory of JRC-IRMM, through its two complementary accelerator based neutron measurement facilities, is the main provider of high quality neutron data in Europe for nuclear safety applications. The action has an important impact on new evaluated nuclear data files in application libraries that are used by nuclear research establishments in Europe and industry. Important recent examples are the Joint Evaluated Fission and Fusion nuclear data file – JEFF – of which version 3.1 was adopted by nuclear industry (AREVA-NP and SERCO), and the United States' Evaluated Nuclear Data File, version ENDF/B-VII.

Priorities and specific objectives for new measurements in the field of community policy were determined through sensitivity analyses of Generation IV (and III) systems combined with an assessment of the status of the nuclear data. This effort was summarised as a number of high priority requests to be found at www.oecd-nea.org/html/dbdata/hprl (HPRL- High priority request list for nuclear data, coordinated by the action leader). These requests provided and continue to provide an important focus for nuclear data research and are important guidance for the tasks of this action and for many related DG-RTD and EU MS projects. Through

many of its consultancies the action's lead role in setting priorities for nuclear data development in Europe are evident.

Research and development in the fields of reactor safety, waste minimisation and sustainability of nuclear energy focus on plant life-time extension, increasing nuclear fuel economy (higher burnup), recycling and/or transmutation of spent fuel, and enhanced safety features. For the accurate modelling and simulation of nuclear power installations there is a need for significantly improved nuclear data and their correlated uncertainties (covariance matrices). The contributions of the action to these aspects which are given below place it firmly in the vision and framework set by the Strategic Research Agenda (SRA, 2009) and its successor the Strategic Research and Innovation Agenda (SRIA 2013) of the Sustainable Nuclear Energy Technology Platform SNETP.

2. History and development of the Action:

This action is a direct successor of the FP6 Action 4241 "*Neutron data for waste transmutation and safety of different reactor systems".* It has evolved from addressing nuclear data priorities used in design safety analyses of dedicated facilities (accelerator driven systems) for waste transmutation to facilities designed for the minimization of high level waste by recycling in innovative designs (Generation-IV fast reactors and double strata scenarios). These scenarios also gained interest in the context of sustainability and enhanced safety features. In doing so it has followed the interests expressed in the Strategic Research Agenda (SRA) of the Sustainable Nuclear Energy Technology Platform (SNETP).

After 2011 the action developed a post-Fukushima project on request of researchers of the Japanese Atomic Energy Agency. This project concerns the development of a non-destructive characterisation method to quantify the U-235 and Pu-239 content of decommissioned debris from the melted cores of the Daichii reactors. This project covers several years and continues under Horizon 2020.

The action has acquired an important role in advertising and following up on high priority nuclear data needs, evidenced by sensitivity analysis of present and advanced reactor concepts and the fuel cycle. The action leader coordinates the maintenance of the OECD Nuclear Energy Agency's (OECD-NEA) High Priority Request List for Nuclear Data (HPRL). The action also strengthened its role in coordinating European Projects and in the Joint Evaluated Fission and Fusion nuclear data library coordinated and maintained by the Databank of the OECD-NEA.

The action evolved to actively take part in transnational access to EU infrastructure. It made important contributions to the newly established transnational access NUDAME and EUFRAT schemes providing access to the JRC neutron measurement infrastructure in Geel and the EFNUDAT and ERINDA transnational access schemes to European neutron measurement research infrastructure (here Coordination of the JRC activities were part of the action 51401).

The action evolved to contribute to training and education activities beyond the supervision of on-site PhD and postdoctoral (cat 30 grant holders and contract agents) students through organising on-site courses at master, PhD, postdoctoral and vocational level (SARA, BNEN, ENEN) and by contributing lectures to courses organised by EU and international partners (Joint Universities Accelerator School at CERN, ICTP/IAEA courses in Trieste).

To remain at the cutting edge of neutron measurements the action actively develops new measurement equipment and data measurement and analysis methods. This is facilitated through collaborations with experts in and outside Europe.

The action aligns its competences and mandate under the EURATOM treaty with recent Commission policy and council directives, in particular with

- COM 2011 563 1st Situation Report on Education and Training in the Nuclear Energy Field in the EU
- C 2011 70 COUNCIL DIRECTIVE 2011/70/EURATOM of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste
- C 2010 212 Council Decision 2012/212/CFSP of 29 March 2010 relating to the position of the European Union for the 2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons
- C 2009 71 Council directive 2009/71/Euratom of 25 June 29 establishing a Community framework for the nuclear safety of nuclear installations.
- COM 2008 312 Communication from the commission to the council and the European Parliament addressing the international challenge of nuclear safety and security
- COM 2005 302 Commission Regulation (Euratom) No 302/2005 of 8 February 2005 on the application of Euratom safeguards - Council/Commission statement

3. Description of the Action

3.1. Clients and Stakeholders

- ANSALDO NUCLEARE S.P.A.
- Atomic Energy of Canada Limited (Canada, AECL)
- Belgian Nuclear Research Centre (SCK-CEN)
- Commissariat à l'Énergie Atomique (France, CEA)
- Centre National des Recherches Scientifiques (France, CNRS)
- Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (Spain, CIEMAT)
- Department of Energy (United States, DOE)
- FGFAF - Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung E.V.
- Helmholtz-Zentrum Dresden Rossendorf e.V. (HZDR)
- International Atomic Energy Agency (IAEA)
- Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
- Israel Atomic Energy Commission (IAEC)
- Istituto Nazionale di Fisica Nucleare (Italy, INFN)
- Institute for Nuclear Research and Nuclear Energy (Bulgaria, INRNE)

- Jozef Stefan Institute (Slovenia, JSI)
- Japan Atomic Energy Agency (JAEA)
- Karlsruhe Institute of Technology (KIT)
- Korea Atomic Energy Research Institute (KAERI)
- Member States of the European Union (MS EU)
- National Institute for Physics and Nuclear Energy (Romania, IFIN-HH)
- Nuclear Physics Laboratory (United Kingdom, NPL)
- Nuclear Research Group (The Netherlands, NRG)
- Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD-NEA)
- SERCO (UK)
- SOREQ Nuclear Research Centre (SRNC)
- United Kingdom Atomic Energy Authority (UKAEA)
- Universities (Birmingham, Bordeaux, Canberra, Debrecen, Dresden, Frankfurt, Gent, Grenoble, Jerusalem, Milano, Michigan, München, Prague, Strasbourg, Wien)

3.2. Major Objectives, deliverables and impacts

The objectives for the reporting period varied in their formulation. Aggregate objectives are shown here that help to demonstrate the underlying consistency of the Action's programme. For each aggregate the corresponding objective numbers are given.

Objective 1: To contribute reference data and measurements for safety, security, safeguards, waste minimization and innovation in nuclear energy through measurements, and measurement-analyses. This is our core activity covering existing nuclear facilities and innovative concepts under development for waste minimisation and sustainability of nuclear energy (Gen-II, III and -IV). (WP Objectives 2007-01, 2008-04, 2008-05, 2008-09, 2008-10, 2009-02, 2010-01, 2010-02, 2010-03, 2011-01, 2011-02, 2012-01, 2013-01).

Main deliverables

(1) Criticality control materials (control rods, neutron poisons). Based on accurate capture and transmission data for Cd and Hf determined at the GELINA facility new evaluated files were made in close collaboration with the stakeholders (SERCO, CEA, IAEA, JSI, OECD-NEA) incorporating feedback form benchmark testing. The files were adopted by the JEFF library (JEFF-3.1.1, JEFF-3.1.2 and JEFF-3.2) and partially adopted by the US ENDF/B-VII.1 library. The data were published in a scientific journal.

(2) Gen-II,-III and-IV (advanced) materials criticality safety and activation data.
   (a) Neutron capture and transmission data were obtained at GELINA for ^{55}Mn, Cu isotopes, Zr isotopes, and W isotopes and in close

collaboration with the stakeholders (US DOE, CEA, JSI, KIT, OECD-NEA, IAEA) evaluated files were produced, tested and finally adopted in the JEFF-3.2 library (Mn, Cu, W) and the ENDF/B-VII.1 library (Mn, Cu, W).

(b) Neutron inelastic scattering data were obtained for ^{23}Na, ^{28}Si, ^{52}Cr, ^{56}Fe, Zr and Mo with the newly developed GAINS array at GELINA, delivered to the ANDES project, stakeholders in Europe (CEA, NRG, KIT) and the US (BNL, LANL) and after publication (Na, Si, Cr) to the EXFOR database (OECD-NEA, IAEA). The results for Na and Cr were incorporated in the latest release of JEFF-3.2. Neutron elastic scattering data were obtained for deuterium and delivered to the stakeholder (AECL) and published.

(c) Neutron activation data were obtained at the IRMM Van de Graaff for Zr, Hf, Ta, W reported and delivered to the stakeholders (UKAEA, CEA, KIT, OECD-NEA, IAEA).

(3) Gen-II, -III and-IV actinide data.

(a) Am-241 capture, total and (n,2n) cross section measurements were completed, analysed, published and incorporated in a 241Am evaluated data file adopted in the JEFF-3.2 library with the stakeholders (CEA, INRNE, OECD-NEA, LANL, ANDES project).

(b) U-238 capture cross section measurements were completed and analysed and confronted with earlier work and concurrent work at CERN n_TOF.

(c) Pu-240, -242 fission cross sections were measured at the van de Graaff accelerator and delivered to the ANDES competitive project.

(d) The data measured for Th-232 capture and transmission and Pa-233 fission were delivered to the IAEA Coordinated Research Project on the Th/U fuel cycle and published as an IAEA report.

Impacts

(1) See section 3.3. Major Highlights item 1 showing that the main deliverables of this objective impacted the libraries JEFF-3.1.1, JEFF-3.1.2, JEFF-3.2 (OECD-NEA) and ENDF/B-VII.1 (USA), while JEFF-3.1.1 and -3.1.2 were adopted by EU industry). The Th/U data are incorporated in IAEA evaluated files and accessible through the IAEA website to all interested. The activation cross section data are incorporated in the European Activation File released in 2010 (EAF-2010, OECD-NEA). The Am-241, U-238 and Pu-240,-242 data were reported to the ANDES Competitive Project.

(2) Accurate cross sections for inelastic scattering are among the priority needs for advanced reactors. Detailed sensitivity studies were performed to analyse their impact and tight requirements emerged (from 2 to 7% depending on the isotope and reactor system). Feedback on the Na results indicate good performance in CEA benchmarks, while for Fe the debate does not appear to be settled. The lead role of the action's activities is emphasized through a CNRS-JRC-"IFIN-HH"-CEA collaboration with a French setup installed at GELINA for the study of actinides inelastic scattering, the prominent appearance of this activity in EU projects (ANDES, CHANDA, EUFRAT, NUDAME), new initiatives for scattering studies at HZDR and PTB (Germany) as well as RPI (USA) and LANL which were catalysed through a new

workshop (WINS) to which the action is coorganizer. An IAEA consultants meeting on this topic was co-chaired by the action leader.

Objective 2: To support post-Fukushima JAEA safeguards research by development of a technique for non-destructive analysis of melted fuel (2013-01).

Main deliverables

(1) Report on the impact of particle size on the reliability, accuracy and uncertainty of the neutron transmission and capture method.

Impacts

(1) See section 3.3. Major Highlights item 2.

Objective 3: To improve measurement equipment and capabilities and to standardize and develop reference data measurements (2007-07, 2007-08, 2007-09, 2008-07, 2008-12, 2009-04, 2009-05, 2011-03, 2011-04, 2012-02, 2013-03).

Main deliverables

(1) Standardisation of measurement and data analysis methods for capture and transmission measurements in the resonance region. Data reduction and uncertainty propagation of time-of-flight spectra with AGS (Analysis of Geel Spectra).

(2) Method development and testing for the Gamma Array for Inelastic Neutron Scattering – GAINS and for neutron-deuterium elastic scattering measurements.

Impacts

(1) Accuracy requirements of high priority requests are so tight that they require significant improvement in data measurement and analysis methods and a standardisation thereof. The methods and software developed for measurement reporting and data analysis are recognized at the international level as new standards for the field. Reports to the OECD-NEA and IAEA testify to this point, standards were adopted by the IAEA and the NRDC (Nuclear Reaction Data Centres), the AGS code was made available to interested parties and an expert group SG36 on Evaluation of experimental data in the resolved resonance region was initiated by the action responsible for this task.

(2) GAINS greatly facilitates the measurement of inelastic scattering cross sections at the GELINA facility, which is of interest to advanced reactor data needs and the methods developed provide the confidence required for their inclusion in new evaluated files (see Objective 1). The reliable new elastic scattering data for deuterium confirm the latest US evaluation and have led AECL to investigate other potential causes of discrepancies in CANDU related benchmark experiments.

Objective 4: To strengthen the impact of the action's outputs and programme by consultancies and networking, co-ordination of collaboration agreements, co-

ordination of competitive projects, provision of transnational access to JRC measurement infrastructure (2007-04, 2007-05, 2007-06, 2007-10, 2008-13, 2008-14, 2008-15, 2008-16, 2009-06, 2010-05, 2010-06, 2011-05, 2011-06, 2012-03, 2013-04).

Main deliverables

(1) Experimental conditions for EUFRAT external users (neutron beams, experimental equipment, data taking support, data transfer). Stakeholders: from CEA(FR), CNRS (FR), ENEA (IT), Goethe-University Frankfurt (DE), HZDR (DE), IFIN-HH (RO), INFN (IT), INRNE (BG), JSI (SLO), KIT (DE), LNL (IT), University of Birmingham (UK), University of Sevilla (ES).

(2) Final report for the Integrated Project EUROTRANS (2010), Program definition, interim and final reports for the Coordinated Project ANDES as coordinator of the Task Measurements for Advanced Reactor Systems. Program definition for the Integrated Infrastructure Initiative CHANDA as member of the executive board and coordinator of 1/3 of the resources. JRC deliverable reporting for ANDES and EUROTRANS and for the transnational access experiments of the action in ERINDA.

(3) Report "Long-term nuclear data needs" by the action leader on the recommendations for the IAEA Nuclear Data Section (NDS) emerging from a IAEA Technical Meeting of experts in the field of nuclear data for applications; Participation in the IAEA Nuclear Data Committee to evaluate and recommend projects of the NDS (2010, 2012); Participation in the JEFF project as chairman of the Experiments Working Group and as member of the Scientific Coordination group for the dissemination of project deliverables and for recommendations on improved evaluations and the JEFF strategy; Participation in the Working Party on international nuclear data Cooperation (WPEC) of the OECD-NEA for dissemination of project deliverables and for recommendations on future projects.

Impacts

(1) Transnational access: Direct contribution to the needs of European and international stakeholders and enhanced visibility for the JRC neutron measurement activities. External contacts help develop the action programme technically and thematically. External users amplify the use that may be made of JRC neutron measurement infrastructure (they bring additional staff, equipment, samples, and experience). Important examples are the measurement setup and programme of CNRS Strasbourg for the study of actinide inelastic scattering and new equipment in the form of single-crystal artificial-diamond detectors for neutron field characterisation by ENEA Frascati.

(2) The important role of action staff in European and International projects and in particular in project coordination testify to the leading role of the action in the domain of its core competence (see also 3.3 Main Highlights, items 3 and 4).

3.3. Major Highlight(s)

Major highlights (up to about 1 per year)

1. International standardisation in nuclear data for safety analyses: Contributions to the JEFF library of the OECD-NEA (Nuclear Energy Agency) for and with Member States have led to the publication of JEFF-3.2, February 2014. The new library competes well with well-known libraries maintained in the USA and in Japan. JEFF data files (version 2.2 and now 3.1.1 and 3.1.2) are widely used in Europe by nuclear industry, regulatory organisations and research organisations. JEFF-3.2 is a significant improvement over the current release and is expected to gradually replace the current release with its users. JEFF contributes to standardisation in nuclear safety through its widespread use in Europe. Through NEA it is known world-wide. The library includes new evaluated data files incorporating essentially all results of Objective 1.

2. Post Fukushima Safeguards support to JAEA (Japan Atomic Energy Agency) by Nuclear Resonance Densitometry: The project aims at a new practical technique for non-intrusive characterisation of the melted fuel of Fukushima Daichii. This technique will allow a simplified nuclear materials accounting during the decommissioning of the reactors which were damaged following the 2011 tsunami. JAEA staff visited IRMM to be trained in the software developed at IRMM for the densitometry technique and to participate in the measurements. Experiments are carried out at the IRMM GELINA facility to characterise the method for particle size and density effects. At the JAEA/EURATOM coordination meeting 30-5-2013 (Bruges) the project was enlarged to include a demonstration activity to be carried out at GELINA in 2015.

3. Serving Member States interests in Safe and Sustainable Nuclear Energy through Nuclear Data Collaboration coordinated by RTD. The action leader, unit head and action staff had lead roles in the formulation and coordination of the CHANDA Integrated Infrastructure Initiative (2013-2017) which constitutes a new pan-European network of nuclear data research facilities and organisations aiming at collaboration in the interest of safety of nuclear energy. This lead role in CHANDA follows the successful project and coordination contributions to the ANDES Coordinated Project (2010-2013) aimed at improving nuclear data for nuclear waste management strategies involving transmutation of high level nuclear waste and made considerable progress towards the reduction of uncertainties needed for reliable safety estimates.

4. Prioritization. The action leader is coordinator of the OECD-NEA Expert Group in charge of the High Priority Request List for nuclear data (HPRL). The HPRL role for nuclear data research and development in Europe is significant emphasizing the importance of currency and quantitative underpinning of requests for nuclear energy. First, this list helps define action 51401 and 51402 objectives and deliverables. Second, several DG-RTD and national projects use the HPRL as reference for defining projects. DG-RTD funded projects referring to the HPRL are CHANDA (CHAllenges in Nuclear Data) ANDES (Accurate Nuclear Data for nuclear Energy Sustainability), METROFISSION (Metrology for fission), ERINDA (European Research Initiative for Nuclear Data for Applications), EFNUDAT (European Facilities for Nuclear Data for Transmutation) and CANDIDE (Co-

ordination Action for Nuclear Data for Industrial Development, 2007-2008). The national projects are NEEDS (Nucléaire: 'energie, environnement, déchets, société, France), GEDEPEON (GEstion des DEchets et Production d'Energie par Options Nouvelles, France) and TRAKULA (Transmutationsrelevante kernphysikalische Untersuchungen langlebiger Aktinide, Germany).

4. Further Information

4.1. Integration and Networking

Collaborations within the JRC. The action is closely linked with action 51401 ND Standards through context, customers and stakeholders, staff and the use of facilities. Important benefits are drawn from action 53102 METRO that is responsible for the production and characterization of the samples used for the measurements of the action. The action benefits from radionuclide measurement support provided by action 51603 RADMET.

International collaboration.

OECD-NEA. The action interfaces with the developers of the JEFF nuclear data library twice per year through progress meetings organised by the OECD-NEA. The action interacts with developers of the US, Chinese, Japanese, and Russian nuclear data libraries through yearly meetings of the Working Party on Evaluation Cooperation WPEC of OECD-NEA and with reactor scientists around the world through the yearly meeting of the Nuclear Science Committee of the OECD-NEA. The action is involved in several working groups (subgroups) of WPEC: it shares the permanent Subgroup C, responsible for the High Priority Request List for nuclear data; it took part in Subgroup 26 on the prioritization of nuclear data needs for advanced reactors and takes part in follow up subgroups 31 and 33 that aim at meeting those needs. A member of the action initiated Subgroup 36 on Evaluation of experimental data in the resolved resonance region. With this and subgroup 40 collaborative International Evaluated Library Organisation Pilot Project the action was an active contributor to standardisation in the development and use of nuclear data at the international level.

IAEA. The action has strong links to the IAEA Nuclear Data Section contributing to its projects and advising on its course of action. The action took part in Coordinated Research Projects organised by the Nuclear Data Section of the IAEA ("Minor actinide neutron reaction data – MANREAD" and the "Reference database for Neutron Activation Analysis"). Bilateral collaboration with the IAEA was initiated to allow the representation of covariance data from time-of-flight data in an accurate and economic way and to further standardise the representation of time-of-flight data in the EXFOR database. The action leader is a member of the International Nuclear Data Committee advising the IAEA Nuclear Data Section. The action leader is the editor of "Long-term Nuclear Data Needs" an IAEA Technical Meeting of international experts advising the IAEA Nuclear Data Section on its long-term course of action. He was also co-editor of a consultants meeting on scattering and capture data for the major actinides.

Bilateral collaborations.

The action supports the US Department of Energy measuring nuclear data for criticality safety at the GELINA facility and is part of the multi-annual work program of the US partner. The action has a project on neutron-deuterium scattering under the EURATOM-AECL collaboration agreement. Since 2011 the action has a project with JAEA on post-Fukushima research for the development of a characterisation technique needed in the decommissioning strategy of melted fuel. Joint activities with CEA, CNRS, IFIN-HH (RO), INFN(IT), INRNE (BG), NTUA(GR) involving measurements at the JRC neutron facilities were supported by Collaboration agreements (CA 31746 - 16/04/2010 INFN, CA31334 CNRS-IN2P3 - 2009/09/01, CA31067 – 2008/10/06 NTUA, CA30836 – 2008/06/20 CEA, CA 2007/07/27 IFIN-HH, CA 2007/07/23 INRNE,). The action engaged in a “Projet International de Cooperation Scientifique – PICS” funded by CNRS and involving CNRS-Strasbourg, IFIN-HH (RO) and IRMM and our common work on improved nuclear data for (n,xng) reactions important to advanced reactors.

4.2 List of Competitive Activities

ANDES, Accurate Nuclear Data for nuclear Energy Sustainability (Grant no. FP7 – 249671, DG-RTD Nov. 2010 - Oct. 2013). ANDES addresses nuclear data studies related to the sustainability of nuclear energy. The “Vision report” and “Strategic Research Agenda” of the European Technological Platform for Sustainable Nuclear Energy (SNETP) require data development for a combination of the present Light Water Reactors, future Advanced Fast systems (critical reactors or subcritical Accelerator Driven Systems) and waste minimization in closed fuel cycles using Partitioning and Transmutation technologies. The action leader and the JRC team working on action 51402 had a major role in ANDES. The action leader was member of the management board and let the project on Measurement for Advanced Reactor Systems, covering 1/3 of the ANDES resources. A considerable contribution was made to the ANDES deliverables.

EUFRAT, European Facility for Innovative Reactor and Transmutation Neutron Data (Grant no. FP7 – 211499, DG-RTD, Nov. 2008 – Oct. 2012). EUFRAT Facilitated transnational access to users of the JRC neutron measurement facilities. It provided nearly 6000 hours of beam time to 33 experiments by visitors from 32 organisations and universities working on EURATOM policy relevant topics. Experiments for EUFRAT were actively supported by action staff. EUFRAT was coordinated by action 51401.

CHANDA – solving CHAllenges in Nuclear DATa (Grant no. FP7-605203, DG-RTD, Dec. 2013 – Nov. 2017). CHANDA is a first pan-European Integrated Research Infrastructure Initiative for increased safety of nuclear systems at EU level. It combines nuclear data projects such as ANDES and nuclear data transnational access such as EUFRAT and ERINDA. CHANDA is geared towards improving research infrastructure and a better integration of the European research, considering the possibility of joint programming. The action had a major role in defining the project and has a major role in its coordination (1/3 of the resources are coordinated by the action leader, 2/3 of the transnational access activity is coordinated by action staff and the action leader is member of the executive committee).

ERINDA European Research Infrastructures for Nuclear Data Applications (ERINDA), 2009-2012. The ERINDA project aims for a coordination of European efforts to exploit up-to-date neutron beam technology for novel research on advanced concepts for nuclear fission reactors and the transmutation of radioactive waste. The ERINDA consortium groups 13 partners equipped with nuclear data research infrastructures. The proposal unifies facility management, research community and stakeholders. The aim of ERINDA is to integrate all infrastructure-related aspects of nuclear data measurements and to provide access for external user to the participating facilities.

EFNUDAT European Facilities for Nuclear Data Measurements, 2007-2010. The EFNUDAT project aims at networking experimental facilities in Europe for nuclear data measurements providing a platform for better co-operation. The objective is to provide adequate trans-national access to the infrastructures and to co-ordinate joint research projects and S-T developments in support to other projects in the NUWASTE-2 programme.

EUROTRANS European research Programme for the transmutation of high level nuclear waste in an accelerator driven system (EUROTRANS), 2005-2010. The EUROTRANS project is devoted to transmutation of high-level waste, focusing on transmutation in an Accelerator Driven System (ADS). The objective is the design and the feasibility assessment of an industrial ADS prototype dedicated to transmutation. The work is carried out by a consortium of 29 partners from 14 countries.

4.3. Mobility and training of researchers

The action supported mobility of researchers in the form of Detached National Experts from Romania (2) and to training and mobility for laureates from Belgium (2), Italy (1), PhD students from Belgium (1), Italy (1), Slovenia (1), Spain (1), Sweden (1) and to postdoctoral students from Belgium (1), Bulgaria (2), Czech Republic (1), Germany (1), Greece (2). A considerable amount of the work of the action is carried out by this temporary staff. PhD students with a thesis based on measurements at the JRC under our support were (1) Belgium, (1) UK, (1) France, (1) Israel, (1) Italy.

Miscellaneous training activities

- Belgian Nuclear Education Network (BNEN), 15.-16. December 2010, Geel, Advanced seminar on accelerators and time of flight experiments, 17 participants
- Second Nuclear Resonance Analysis School (14-18 November 2011, Geel, 45 attendants EU Member States, USA, Japan, Korea, China, India, IAEA co-organiser, OECD-NEA co-organiser).
- SARA 2012, 22.-23. March 2012, Geel, Advanced training course - Accelerators and time-of flight experiments, 23 participants
- BNEN 2013 (21.-22. March 2013) Advanced training course - Accelerators and time-of flight experiments, 11 participants
- Contributed lectures to
    - Joint Universities Accelerator School, CERN, annually 2010-2013.
    - Accelerator engineering course, U. Gent, annually 2010-2013, 6 ECS points.

- Lecture 'Techniques for Nuclear Data Measurements', 4-6 October 2010, PTB Braunschweig, Germany (TRAKULA Graduate Seminar Experimental systems and methods for transmutation research).
- Lecture "Cross section measurements and uncertainties of cross section data" at the International Centre for Theoretical Physics, for the ICTP-IAEA workshop on Nuclear Reaction Data for Advanced Reactor Technologies, 3-14 May 2010, Trieste, Italy.
- 525. Heraeus-Seminar "Nuclear Physics Data for the Transmutation of Nuclear Waste", February 25-27, 2013, Bad Honnef, Germany

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) January 2007 – December 2013

Action *51502 AIT*
Alpha-immunotherapy
Action Leader: *Alfred Morgenstern - Nuclear Chemistry*

Authorising Officer: *Jean-Paul Glatz - Nuclear Chemistry*
Leading Institute: *Institute for Transuranium Elements (ITU)*

0. Policy Area

FP7 Policy Theme: 5 The EURATOM programme
Agenda No & Title: 5.1 Nuclear waste management and environmental impact
Sub-Agenda No & Title: 5.1.5 Medical applications from nuclear research

As stated in the Commission's 2007 Nuclear Illustrative Programme (Communication from the Commission to the Council and the European Parliament "Nuclear Illustrative Programme", COM(2007) 565, 4 October 2007), medical uses of ionizing radiation are becoming increasingly important, but these new technologies also administer ever-increasing radiation doses to the patient. Subsequently, in its communication to the European parliament and the council on medical applications of ionizing radiation and security of supply of radioisotopes for nuclear medicine (COM(2010)423 / 12848/10 ATO 45 SAN 163), the commission has identified key challenges in this area, in particular:

- improving radiation protection of patients and staff,
- securing supply of radioisotopes for nuclear medicine.

In response to the above challenges and taking into account the existing instruments under Euratom and EC provisions, the Commission has proposed various actions, including fostering radiation protection and sustainable supply and use of radioisotopes in medicine through research.

In the Commission Staff Working Document Accompanying the Communication (*SEC(2010)974 / ADD 1*), JRC-ITU, using its unique facilities and expertise in handling highly radioactive alpha-emitting nuclides to develop, produce and test novel methods for cancer treatment has been identified as one of the main EU instruments relevant to the medical applications of ionizing radiation.

Furthermore, in the conclusions from its meeting "Towards the Secure Supply of Radioisotopes for Medical Use in the European Union" (3053rd EMPLOYMENT, SOCIAL POLICY HEALTH and CONSUMER AFFAIRS Council meeting, Brussels, 6 December 2010) the COUNCIL OF THE EUROPEAN UNION has advised the Commission to work further with relevant EU instruments to the appropriate medical applications of ionizing radiation, stressing the need for continued efforts to actively investigate economically feasible alternatives to the current radioisotope production methods and the isotopes currently used.

Also in its conclusions from the meeting on the security of supply of radioisotopes for medical use (2986th AGRICULTURE and FISHERIES Council meeting, Brussels, 15 December 2009) the Council invites the Commission and the Member States to look into possibilities of promoting the further development of techniques in nuclear medicine which can be applied without using nuclear reactor-produced radioisotopes.

In summary, the communications of the European Commission and the conclusions drawn by the European councils represent the mandate to develop novel (in particular non-reactor driven) methods for production of medical radionuclides, to investigate alternative nuclides to the ones currently used and to provide training and education for the safe handling of radionuclides in clinical settings. In this context

JRC-ITU is pointed out as one of the main EU instruments to carry out these tasks under Euratom provisions.

1. Rationale of the Action:

The Alpha-immunotherapy (AIT) action is addressing the key challenges identified by the commission through the development of (non-reactor driven) methods for the production of novel alpha emitters and radionuclide generators and the provision of training and radiochemical support to hospitals to enable the safe use of alpha emitters in clinical settings. In addition, the action is conducting pre-clinical studies and clinical trials in collaboration with a large number of hospitals and cancer research centres in Europe, USA and Australia for the benefit of cancer patients worldwide, thus contributing to all stages of the development of targeted alpha therapy (TAT) from bench to bedside,

TAT is a novel and promising method for the treatment of cancer and infectious diseases. TAT is taking advantage of the unique physical properties of alpha radiation, in particular its high energy and short path length in human tissue, to selectively address and destroy diseased cells while sparing surrounding healthy tissue. TAT is offering a new treatment option to cancer patients that are not responding to conventional treatments, including chemotherapy and therapy with beta emitters.

2. History and development of the Action:

AIT is a mature action which, based on JRC-ITU's unique facilities for the handling of highly radioactive alpha-emitting nuclides, initially focused mainly on the development of methods for production of therapeutic nuclides. Subsequently, the activities were expanded towards the conduction of multiple pre-clinical and clinical studies and the dissemination of knowledge to clinical partners through increased training and education efforts.

3. Description of the Action

3.1. Clients and Stakeholders

The action provides radionuclides and radionuclide generators, radiochemical support as well as training courses on the safe handling of alpha emitters to its clients in various hospitals and cancer research centres in Europe, USA and Australia. In FP7 these clients include University Hospital Heidelberg, Technical University Munich, University Clinical Centre Ulm, University Hospital Mainz, (all Germany), Medical University Warsaw (Poland), Institut National de la Santé et de la Recherche Médicale (France), University Hospital Gothenburg (Sweden), University Hospital Basel, Paul Scherrer Institute, (both Switzerland), Delft University of Technology, Erasmus Medical Centre Rotterdam (both The Netherlands), Albert Einstein College of Medicine, Johns Hopkins School of Medicine, Rutgers University (all USA) and St. George Hospital (Australia).

The action took part in the FP7 collaborative project TARCC (Targeting Alpha-Emitting Radionuclides to Combat Cancer), within the policy area HEALTH-2007-2.4.1-7 (Improving targeted drug delivery to cancer cells for cancer therapeutics other than gene therapy), and acted as work package coordinator. TARCC is financed by DG-RTD.

In collaboration with University Hospital Düsseldorf the action has conducted and finalised the research project "Mechanisms of cytotoxicity induces by alpha-radiation in normal and malignant hematopoietic cells" (project 02S8213) financed by the German Ministry of Education and Research.

3.2. Major Objectives, deliverables and impacts

Objective 1: Development of methods for production of alpha emitters for clinical use

The alpha emitters actinium-225 / bismuth-213 are the most promising radionuclides for application in TAT. The action has developed and continuously improved radiochemical and cyclotron driven methods for the production of Ac-225/Bi-213 in clinical grade purity. A novel high-activity type of Ac-225/Bi-213 generator was developed and successfully validated loaded with up to 4 GBq Ac-225. During FP7 215 quality controlled shipments of radionuclides and radionuclide generators were produced and provided to hospitals in Europe and world-wide along with radiochemical support.

The alpha emitter uranium-230 and its daughter nuclide thorium-226 are novel radionuclides for application in targeted alpha therapy. The concept of applying these isotopes as therapeutic radionuclides was first proposed and patented in the frame of this action. In FP7 four novel cyclotron driven processes for the production of these nuclides have been developed. Excitation functions for the reactions Th-232(p,3n)Pa-230(□)U-230, Pa-231(p,2n)U-230, Pa-231(d,3n)U-230 and Th-230(He-3,3n)U-230 have been measured. The cross sections for reactions on Pa-231 and Th-230 could be reported for the first time. Thick targets from Th-232 and Pa-231 for production purposes have been manufactured and irradiated. The Th-232 based process has been identified as most promising and has been up-scaled to a production level relevant for clinical studies. The first U-230/Th-226 radionuclide generator has been developed and validated. Several *in vitro* studies have been performed demonstrating the high therapeutic efficacy of the novel therapeutic nuclides, and the first *in vivo* testing in an animal model of bladder carcinoma could be conducted in 2008.

Objective 2: Conduction of preclinical studies and clinical testing

A large number of pre-clinical studies on breast, prostate, ovarian, pancreatic and bladder carcinoma, multiple myeloma, neuroendocrine tumours, leukaemia as well as on infectious diseases, including bacterial, fungal and viral infections (HIV infections), has been conducted in collaboration with clinical partners. In a fundamental study radiobiological study it could be demonstrated for the first time that TAT is effective in killing cancer cells that are resistant to chemotherapy as well as irradiation with gamma and beta radiation and can thus offer a new treatment option to patients refractory to conventional treatments.

The first clinical trials on TAT of brain tumours, neuroendocrine tumours and systemic TAT of malignant melanoma could be conducted in collaboration with hospitals in Switzerland, Poland, Germany and Australia. In FP7 132 cancer patients have been treated in cooperation with clinical partners using JRC-ITU produced radionuclides and radiolabeling protocols. In the vast majority of cases ITU staff also performed synthesis and quality control of the radiopharmaceutical for patient treatment on site.

Objective 3: Improving radiation protection of patients and staff

The action has prepared a training manual on the safe handling, detection and analysis of alpha emitters in clinical settings. It includes guidelines on the safe operation on radionuclide generators with focus on protection of patients and medical staff. Based on the training material, hospital staff in various member states has been trained. The trainees were subsequently capable of handling alpha emitting radionuclides in a safe manner using appropriate protective measures.

In collaboration with an industrial partner, the action has developed a fully automated system for the quality-controlled synthesis of radiopharmaceuticals labelled with the alpha emitter Bi-213 according to Good Manufacturing Practice (GMP). Automation of the radiolabeling process significantly reduces radiation dose to operators in hospital settings.

Objective 4: Publications and awards

The action published 60 publications in peer-reviewed journals, 18 contributions to peer-reviewed conference proceedings and 1 contribution in a monograph. Particular focus is given on publishing results in high ranked journals of high impact. Several outstanding papers were published in *Cancer Research* (impact factor 9.3, 5 publications) and *Angewandte Chemie* (11.3, 2 publications). The action received three times the JRC prize for best peer-reviewed publication (2007, 2009, 2010). In 2008 a joint study with TU Munich received the Marie Curie Award of the European Association of Nuclear Medicine. In 2012 the action has been awarded the prestigious SNMMI Image of the Year Award for the best paper selected from >3000 papers presented at the 2012 Annual Congress of the American Society of Nuclear Medicine.
(http://www.snmmi.org/NewsPublications/NewsDetail.aspx?ItemNumber=8802).

3.3. Major Highlight(s)

Brain tumours have a very poor prognosis and novel treatment options are urgently needed. In 2007 a world-first study on Bi-213 therapy of malignant brain tumours was successfully started in collaboration with University Hospital Basel and is continued in collaboration with Medical University Warsaw. In FP7 40 brain tumour patients were treated up to 8 times. The treatment was found to be safe, without toxic side effects and led to therapeutic responses in all patients. The intermediate analysis of survival data indicates a 50% prolongation of patient survival as compared to conventional treatments. The action was strongly involved in the conception, preparation, conduction and evaluation of this study, in particular through the provision of radionuclide generators, the development of a quality controlled protocol for the synthesis of the radiopharmaceutical as well as the on-site preparation of the radiolabelled drug. The further development of this novel therapy option is an important aim of the action.

The first in human testing of targeted alpha therapy of neuroendocrine tumours has been performed in collaboration with University Hospital Heidelberg (Germany). Neuroendocrine tumours are tumours that develop in the digestive system and are distributed throughout the body. They fall into two main categories—carcinoid tumours and pancreatic endocrine tumours—and are often resistant to standard treatments, such as chemotherapy, hormone therapy and targeted therapy with beta emitters. Overall 26 patients that had developed resistance to standard treatments were treated with the Bi-213 labelled peptide DOTATOC. The treatment was found to be safe, with limited side effects and produced therapeutic responses in all

patients. This work was awarded the prestigious SNMMI Image of the Year Award 2012. The figure below shows an example of a young female patient that presented in a life-threatening situation due to massive growth of liver metastases before treatment and nearly complete remission after TAT, resulting in a significant prolongation of her survival.

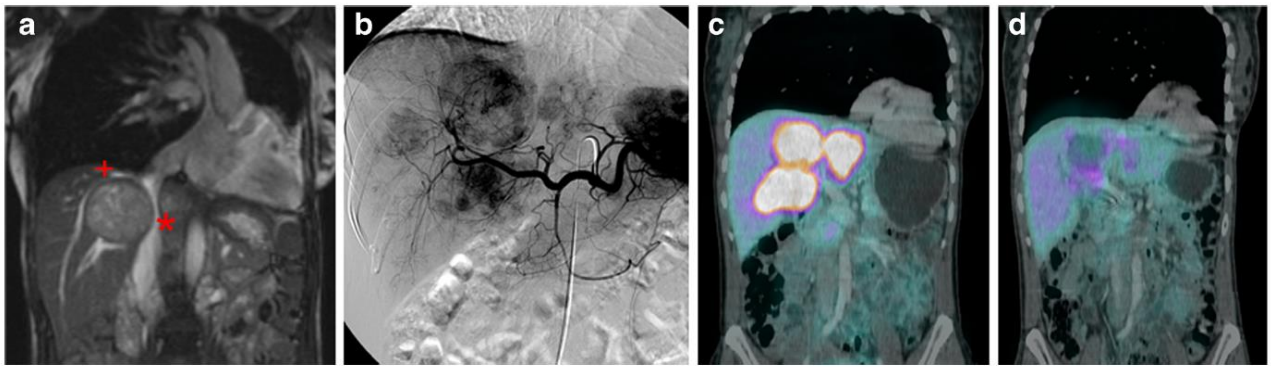

Fig. 1: Patient with acute threat for occlusion of both, liver veins and lower caval vein due to a large lesion in the upper central liver (a, magnet resonance imaging) which could be addressed by loco-regional ^{213}Bi-DOTATOC-therapy administered into the proper hepatic artery (b, digital subtraction angiography). Intense ^{68}Ga-DOTATOC uptake and uptake of contrast media for computed tomography was present in the initial staging (c, PET/CT fusion). Only PET-negative, morphologically cystic residuals were found 6 months after therapy (d, PET/CT fusion).

The first clinical study on Bi-213 therapy of malignant melanoma had been initiated in FP6 in collaboration with St. George Hospital in Sydney, Australia and was finalized in FP7. Within this study, a total of 38 patients with stage IV melanoma were treated using a ^{213}Bi-labelled monoclonal antibody in a dose escalation scheme to study toxicity of the treatment. No adverse events of any type or level were observed, 39% of patients responded to the treatment.

In 2008 a collaborative project of Technical University Munich and the AIT action investigating targeted alpha therapy of bladder carcinoma has received the prestigious Marie Curie Award of the European Association of Nuclear Medicine (EANM). Bladder carcinoma is a very common urological tumour, responsible for about 3.5% of cancer deaths in Europe. In the award winning study an animal model was used that closely mimics the real patient situation. Treatment with Bi-213 has shown excellent response rates and significantly increased survival of treated animals compared to those that received conventional chemotherapy or no treatment. Based on the promising results of this study the clinical testing of this novel approach has been started in 2014 in collaboration between Technical University Munich and JRC-ITU with the treatment of 6 bladder carcinoma patients.

Resistance to conventional therapy, including chemo- and external beam therapy is a frequent cause for failure in the treatment of leukaemia. In a collaborative project of this action with University Hospital Ulm it could be demonstrated for the first time that targeted alpha therapy can overcome chemo- and radiation resistance and consequently offers a new therapy option. In the study, leukaemia cells that were resistant to chemotherapeutic drugs (doxorubicin) or gamma- or beta radiation could

be selectively targeted and destroyed using a monoclonal antibody labelled with the alpha emitter Bi-213. The results of the study were published in *Cancer Research*.

4. Further Information

4.1. Integration and Networking

The action is closely collaborating with the cyclotron department of JRC-IHCP, Ispra, focusing on the accelerator driven production of therapeutic radionuclides. In FP7 ten joint publications in peer-reviewed journals were published. A very productive collaboration with the Reference Laboratory for Radionuclide Metrology of JRC-IRMM on the measurement of nuclear data of therapeutic alpha emitters has resulted in 7 joint publications in peer-reviewed journals

Outside JRC the action is presently collaborating with 15 international hospitals and cancer research centres to conduct animal studies and clinical trials. Further collaborations include the Nuclear Physics Institute, Czech Republic (alpha emitter production), the IAEA Nuclear Data Section (nuclear reaction modelling) and Eckert& Ziegler Eurotope (commercial application of TAT).

4.2 List of Competitive Activities

FP7 collaborative project TARCC (Targeting Alpha-Emitting Radionuclides to Combat Cancer), within the policy area HEALTH-2007-2.4.1-7 (2008-2010)

Research project "Mechanisms of cytotoxicity induces by alpha-radiation in normal and malignant hematopoietic cells" (project 02S8213) financed by the German Ministry of Education and Research.

4.3. Mobility and training of researchers

The following researchers were trained within the action:

Trainees: 2

Ph.D. students: 2

Postdoctoral fellows: 4

Visiting Scientists: 2

The action is member of the Marie-Curie Initial Training Network Trace ‘n Treat (http://tracentreat.eu/) providing multi-disciplinary high-quality training to early stage researchers.

Training on the safe handling of radionuclide generators and the synthesis of alpha emitter labelled radiopharmaceuticals was provided to personnel from various European hospitals and research centres.

The action contributed to ITU-organized training courses on radioactivity and radiation (Nuclides.Net) through regular lectures and case studies.

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2013

Action *51601 REM*
Radioactivity Environmental Monitoring
Action Leader: *Marc De Cort, H.04 until 31.12.2010, E.08 from 01.01.2011*

Authorising Officers: *Alois Krasenbrink (until 31.12.2010), Willem Janssens (from 01.01.2011 onwards)*
Leading Institutes: *Institute for Environment and Sustainability (until 31.12.2010), Institute for Transuranium Elements (from 01.01.2011 onwards)*

0. Policy Area

FP7 Policy Theme	5 The EURATOM programme
Agenda No & Title	5.1 Nuclear waste management and environmental impact
Sub-Agenda No & Title	5.1.6 Measurement of Radioactivity in the environment

1. Rationale of the Action:

The role of the European Commission to provide information on the radioactivity levels in the environment is laid down in the EU legislation (*incl.* Euratom Treaty; Council Decision 87/600 on the Community arrangements for the early exchange of information in the event of a radiological emergency; Convention for the protection of the marine environment of the North-East Atlantic (OSPAR) and of the Baltic Sea Area (HELCOM); Drinking Water Directive; Council Regulation No. 3954/87 regarding the maximum permitted levels of radioactive contamination of foodstuffs, Council Directive 2013/59/Euratom: basic safety standards). In addition, there is growing concern within the general public about the radioactivity levels in the environment, as well as the risk of future nuclear accidents. It is evident that in order to provide this information in an efficient, transparent and objective way, an automatic information system is necessary to collect and evaluate environmental radioactivity levels in normal and in emergency conditions, with access rights to a wide audience and managed by an independent organisation.
The REM action started shortly after the Chernobyl accident. It has built up a long-standing experience of European-wide data collection, evaluation and subsequent reporting on environmental radioactivity, continuous monitoring systems and emergency information systems using the best available IT, as well as atmospheric model inter-comparison and tracer experiments. All these activities are mainly organised and carried out in close collaboration with DG ENER as well as other relevant policy DGs (RTD, HOME, DEVCO), with EU28 MSs officials, Candidate countries (Competent Authorities, national laboratories) and other international organisations such as the International Atomic Energy Agency (IAEA).

2. History and development of the Action:

REM implements art. 39 of the Euratom Treaty (see “visible impact of policy support”). It acts as a super-national institution that neutrally collects, validates and reports radiological environmental information from EU Competent Authorities under routine and emergency conditions. The main systems being developed and operated are:
1) The **REM data bank** supports the Community policy, in particular art. 36 of the Euratom Treaty. This states that the EU Member States are obliged to inform the Commission on the levels of radioactive contamination of the various compartments of the environment (air, water, soil). These data (from 1984 onwards) are stored in the REM data base. From these data the environmental radioactivity monitoring reports are produced.
2) The **ECURIE** (European Community Urgent Radiological Information Exchange) system is a communication network between the European Commission and the Member States Contact Points. It is the official EC system to be used for the early notification of a nuclear accident and the subsequent rapid exchange of urgent

information messages. The ECURIE network is the practical implementation of the 87/600 Council Decision. The creation, encoding, decoding and transmission of the messages are done by means of the in-house developed CoDecS (Coding-Decoding Software). It was substituted by a new web-based software, called WebECURIE, in December 2012. REM is responsible for the development of all the ECURIE related software, the user assistance and the training activities.
3) **EURDEP** (European Radiological Data Exchange Platform) is both a data-format for radiological data and a network for the exchange of automatic monitoring data. Currently (2014) it is used by 37 European countries for exchanging data from most European monitoring networks (about 5000 stations) in almost real-time. The required data exchange is done in continuity on hourly basis. The data exchange is mostly done through a mirroring mechanism (pull-system, by which servers from national data providers are regularly scanned for new data files, which subsequently are transferred) using the file transfer protocol (ftp and sftp). The data can be viewed and downloaded by the Contact Points through a web-interface. In addition there is a separate web-site for public access where most of the data (controlled by national data providers for verification purposes) can be viewed. Since 2013, EURDEP actively coordinates with the Incident and Emergency Centre (IEC) of the IAEA to test and establish the International Radiation Monitoring Information System (IRMIS).
4) **ENSEMBLE** (until 31.12.2010), addresses the issue of harmonisation and coherence of emergency management and decision-making in relation to long range atmospheric dispersion modelling. The system developed allows in a short time to acquire, treat and redistribute the results produced independently in various countries and therefore to share information and competences. Under emergency conditions the immediate and direct comparison with other model results allows for the identification of major flaws in the model simulation. Moreover, as relevant element of support to decision making, ENSEMBLE allows one to determine the level of consensus in forecasting the evolution of the dispersing cloud.
As a result of the JRC re-organisation of 1 January 2011, the REM action was reduced to the first 3 activities (REMdb, ECURIE, EURDEP), which were moved to the Institute of Transuranium Elements, whereas the ENSEMBLE activity stayed in the Institute for Environment and Sustainability.

3. Description of the Action

3.1. Clients and Stakeholders

Customer DGs (inside the European Commission):

- DG Energy (ENER)
- DG Migration and Home Affairs (HOME)
- DG International Cooperation and Development (DEVCO)
- DG Humanitarian Aid and Civil Protection (ECHO)
- DG Research and Innovation (RTD)

Customer/users (outside the European Commission):

- EU Member State authorities competent for environmental radioactivity and emergency preparedness and response
- National laboratories and institutes
- International Atomic Energy Agency (IAEA)
- World Meteorological Organization (WMO)
- European Environment Agency (EEA)

- European Parliament

The Action collaborates with Competent Authorities and national laboratories from EU Member States and Candidate Countries. This is also materialised into various operational networks, operated and maintained by REM, *i.e.*

- The REM data base exchanges environmental radioactivity monitoring data between Competent Authorities in EU and the Commission (DG ENER D.3 and JRC).
- ECURIE's network is composed of the EC (DG ENER D.3 and JRC E.08), IAEA (IEC), and EU competent authorities, Switzerland and Croatia.
- EURDEP: 39 organisations in 37 European countries are connected to this network and send their national monitoring data in almost real-time. Intensive collaboration with the IAEA to develop IRMIS.
- ENSEMBLE is a network composed of meteorological centres in 20 countries, mainly in Europe but also in Canada, Japan and USA, which addresses the issue of harmonisation and coherence of emergency management and decision-making in relation to long range atmospheric dispersion modelling.

3.2. Major Objectives, deliverables and impacts

Objective 1: To collect, validate and report on the radioactivity levels in the environment of the EU.

Main deliverables:

- The REM DST (data submission tool) has been designed and is being developed and implemented with and used by the Competent Authorities of the EU MSs to perform on-line submission of their environmental radioactivity measurements. The first version was officially released on 1st May 2007. A second version, with more functionality for the user to verify the way in which the data will appear in the final report, was made available in April 2008, together with the release of a new version of the REM Data Submission Tool manual in which all the new functionality is clearly explained. In addition during the reporting period (2007-2013) 9 practical training courses on the use of the REM DST have been organised to 66 representatives of European Competent Authorities (EU28 and candidate countries).
- Because of the important backlog, special attention and effort was spent to speed up the publication of the Monitoring reports. From 2007 onwards, the Monitoring Reports for the years 2001 – 2003 and for 2004-2006 have been officially published. The report covering the years 2007-2011 has been prepared and is in a final status.
- On 12-13 October 2009 in Ispra, the Radiation Protection Unit of DG ENER and REM organised the biennial meeting of the EU-27 Member States' representatives in the context of Article 35/36 of the EURATOM Treaty, to take stock of progress made in monitoring environmental radioactivity in Europe.
- A new experts working group dealing with the Euratom art 35 and 36 in 2012, was established by JRC, with the agreement of DG ENER. Purpose of this working group is to improve feedback and reporting of environmental radioactivity between the EU Member States and the EC. Three meetings were held in 2012-2013.

Impacts:
Improved and accelerated reporting on environmental radioactivity in the EU.
The exchange and validation of environmental radioactivity monitoring data in the EU is described in the Euratom Treaty (Chapter III, art. 35-36), which also states that this must be done by JRC (Ch. III, art.39).
The results of the collection and validation of the environmental monitoring data by REM are used to inform the national Competent Authorities as well as members of the public (monitoring reports, on-line systems) by DG ENER for its (Euratom art. 35) inspections of national monitoring installations (about 3 EU Member States inspected per year, depending on DG ENER's relevant work programme) and to respond to relevant Parliamentary Questions or to prepare trade agreements (in collaboration with DG SANTE; e.g. Mexico-EU trade agreement on milk in 2007).

Objective 2: To harmonise EC and IAEA systems for international nuclear/radiological emergency communication.

Main deliverables:

- During FP7 REM staff contributed actively to achieve excellent progress in the harmonization efforts with the IAEA. Three years of technical discussions, mainly by means of organising and chairing working group meetings, resulted in an agreed conversion document between the ENATOM (IAEA Early Notification and Assistance Technical Operations Manual) and ECURIE (EC) formats in 2008. During a meeting in Vienna the assurance of the IAEA was obtained that they will use the IRIX (International Radiological Information eXchange) standards for their future developments. This will ensure long-term compatibility between the EU, IAEA and other international information exchange systems.

- As a result of its experience in real-time data exchange in Europe and its long-lasting collaboration with the IAEA (IEC), JRC assists the latter in IRMIS. It provides a test bed for involving and improving the data transfer with IAEA Member States (currently Canada and China)

Impacts:
Within the IAEA Action Plan, the IRIX data-format and data-exchange protocols were discussed and defined in international context and with the IAEA by means of a series of working groups (IAEA/SG-I and EPR(emergency preparedness and response)) leading to a greatly enhanced and improved version of the IRIX standards and the creation of an IRIX Steering Committee in order to assure sustainability of the above standards. In addition, a common data format avoids duplication of reporting for EU Member States, as they have legal obligations both to IAEA and the EC.
By establishing compatible systems, European countries benefit from information exchanged from neighbouring areas for potential close-by accidents, and remote accidents in general (e.g. Fukushima).

Objective 3: To improve the EC systems for exchange of information in case of radiological/nuclear emergency

Main deliverables:

- The EURDEP network for the automatic exchange of radiological monitoring data was continuously extended to reach a total of 39 participating Organizations in 37 countries (2014). The reliability of the data-exchange was further improved by the implementation of the pull-concept in various other countries. On specific request for more confidential data transmissions (expressed by several countries), SFTP and FTPS (S for Secure) was integrated in EURDEP.

- Collaboration with the German radiation protection authority (BfS, Freiburg) and the EURADOS WG3 community (intercalibration of gamma dose-rate detectors) have led to a definition of algorithms to correct the monitoring data for background, cosmic radiation, self-effect, site-characteristic etc.

- Much effort has been dedicated to support activities for DG ENER D.3. On invitation of DG ENER, REM staff has given an ECURIE/CoDecS training courses to the French, Slovak and Croatian Competent Authorities, has co-organised and co-chaired the ECURIE Competent Authorities meetings (bi-annual) and has participated to an extraordinary Competent Authorities meeting to discuss the Krsko and Fleurus accidents. REM also co-organises and chairs the ECURIE-EURDEP Working Group meetings (2-3 per year). Two international EURDEP workshops (Stresa, 17-21 May 2010; Arona, 25-27 March 2013) were organised in which progress and the future developments were presented and discussed with the European data providers, DG ENER, IAEA and CTBTO.

  Intense collaboration with the IEC of the IAEA during FP7 resulted in the world-wide IRIX format, ensuring full compliance with the ECURIE and EURDEP systems. This collaboration further culminated in the assistance of the development and testing of IRMIS and in finding support for a “regional approach” as a concept for world-wide emergency information exchange. In the latter context, EURDEP will continue to operate as a European data hub with the IAEA and JRC’s experience can be used as example in other regions of the world (e.g. in a current H2020 administrative arrangement (DG DEVCO) with South-East Asia for regional cooperation on EPR)

Impacts:

Explicit reference is made to the EURDEP and ECURIE system in the IAEA Report on “Preparedness and Response for a Nuclear or Radiological Emergency in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant”, 2013 (Ch. 5.2.4 and 5.2.5).

The validity and reliability of the ECURIE and EURDEP networks - developed and operated (EURDEP) by REM - were successfully demonstrated during the Krsko and Fleurus nuclear accidents that respectively happened in June and August 2008. During the Fukushima accident (March 2011) ECURIE was not activated, because of the low radiological risk for Europe; the EURDEP system continued to operate normally and was able, except for a few minor exceptions, to handle an increased access-rate from the public.

The information to be exchanged between MSs and the Commission in case of radiological/nuclear emergency is described in Council Decision (CD) 87/600.

According to this description, the emergency information exchange systems developed by REM cover the various aspects and facilitate the exchange of this information between the national emergency centres and the Commission (DG ENER D.3).
Improved emergency response by means of ECURIE software developed with web-technology (national radiological duty officers will be able to respond to ECURIE messages (only internet access is required)), and more efficient message/information handling by means of the "bulletin board concept" of the software.

Objective 4: Intercomparison and evaluation of long range atmospheric dispersion forecasts.

Main deliverables:

- The ENSEMBLE activity strictly complies with the Council Decision 87/600 which defines the need of exchange of model results among other information in case of a nuclear emergency. It puts each participating country in the position of complying with this request in a simple and harmonized way. The activities of ENSEMBLE have received the attention from WMO and IAEA and have been discussed during various working groups on long range atmospheric dispersion modelling for emergency response.

- The coupling of ENSEMBLE with the EURDEP database allows the direct consultation of model predictions and real-time monitoring data in case of an emergency. During 2007, the major line of development focused on the coupling of ENSEMBLE with the EC nuclear emergency information system ECURIE to automate the alert notification to the ENSEMBLE modelling groups. In 2008, a new contract was initiated for the implementation of new specifications requested by the countries. Among them the generalization of the submission format that will allow a more versatile applicability of the system in the context of a.o. emergency response.

- Periodic testing of the ENSEMBLE system has been performed within the framework of a Memorandum of Understanding signed with the IES by 17 meteorological offices and environmental protection agencies currently involved in the ENSEMBLE activities. During the reporting period seven real-time exercises and two exercises with measurements available for testing the air concentration models were performed successfully. A new version of ENSEMBLE was implemented and successfully tested

- Regular international workshops were organised and held at JRC Ispra (14-16 May 2007, 28-30 May 2008 and 10-12 May 2010) for discussing the outcomes of the ENSEMBLE exercises and the scientific progress achieved.

- A special session on the ENSEMBLE project, co-chaired by REM staff, was held at the American Nuclear Society, 2nd International Joint Topical Meeting on Emergency Preparedness & Response and Robotics & Remote Systems (Albuquerque, 2008).

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Impact:
Improved support to meteorological offices and subsequently national decision makers, by allowing them to have access to dispersion forecasts.

Objective 5: Preparation of indoor radon maps in view of the European natural radiation atlas.

Main deliverables:
In collaboration with the National Competent Authorities of the EU Member States, we provide:

- Scientific support to the Competent Authorities in defining scientific procedures to produce harmonized radon maps at European level.

- Scientific support to International bodies for radon related matters: REM was a member of the WHO expert group during 2007 for the evaluation and the coordination of the International Radon Project (IRP, WHO) ending in spring 2008.

- The current European Indoor Radon Map includes data from 25 countries, both EU and non-EU Member States, on a 10 km x 10 km grid across Europe. These data have been aggregated from one-year measurements of radon concentrations on ground floor in buildings, as collected by the National Authorities. This work has been published in several scientific journals; it continues to be updated/completed whenever European countries' Authorities provide additional datasets.

- REM co-organized the "9th International Workshop on the geological aspect of radon risk mapping", and organized a Workshop on geogenic radon mapping in the frame of the 33rd World Geological Congress (Oslo, August 2008), also mentioned as JRC headline of 06/08/2008. Subsequently several international workshops were organised in Ispra (27-29 October 2009; 29 November – 2 December 2011) and sessions in international conferences (Prague Radon Conferences on a biannual basis) were organised to develop procedures to identify radon prone areas in Europe.

Impacts:
Increased public awareness and moderate the concern on the risk of indoor radon by putting natural radioactivity into perspective versus artificial radioactivity. Indoor radon is considered as the second reason for lung cancer after smoking tobacco.
The publication of the atlas will support MSs' authorities in their obligation to inform its population of the dangers of ionising radiation.
The expertise of REM in radon related matters was also acknowledged in the report "WHO Europe (2007). Children's health and the environment in Europe: a baseline assessment. D. Dalbokova, M. Krzyzanowski, S. Lloyd (Eds).

3.3. Major Highlight(s)

The Krsko NPP incident on 4 June 2008 was notified by the Slovenian authorities through the ECURIE network, which is developed by JRC and operated by DG ENER D.3. It was the very first time since the creation of the ECURIE system in 1988 that it was used for a real notification and the entire ECURIE network has very

reliably done for what it is designed: the notification and subsequent exchange of information during a radiological event. At the same time real-time monitoring data and meteorological data were available through the EURDEP network, which is developed and operated by REM. Since there was no direct risk for an atmospheric release, the ENSEMBLE modelling network was not activated. The REM group also took care to provide information and explanations to the official Spokesman of DG ENER via the JRC-PR immediately after and during the days following the event.
REM co-organized the "9th International Workshop on the geological aspect of radon risk mapping", and organized a Workshop on geogenic radon mapping in the frame of the 33rd World Geological Congress (Oslo, August 2008), also mentioned as JRC headline of 06/08/2008. This event identified and stimulated the collaboration with the Member States and paved the way to develop a European geogenic radon map.
The WebECURIE software, fully designed, developed (with external subcontract) and tested in JRC, in close collaboration with EU Member States' Authorities competent for Emergency Preparedness and Response and DG ENER was officially implemented in December 2012. This web-service is the official tool obligatory for EU Member States to exchange information to the European Commission in case of radiological/nuclear emergency. It was tested successfully during the international emergency exercise ConvEx3 (October 2013) organised by the IAEA.

4. Further Information

4.1. Integration and Networking

Together with ITU and IPSC, REM is part of the Administrative Arrangement with DG JLS on "Survey of Radiological Vulnerability in the EU" (Nr. JRC.BXL.30634-2007). The arrangement was signed 6 August 2007 and lasted until August 2008. In the frame of a survey of the radiological preparedness in the EU (AA between DG JRC and DG JLS) the Polish National Atomic Energy Agency was visited (IES and IPSC) to get feedback on the draft questionnaire. This questionnaire was sent to all EU MSs to obtain information on the national situations in view of identifying areas where harmonisation at international level could be improved. The results were analysed and published as a JRC EUR report in September 2008.
The REM Action also collaborates with Action 51603 of IRMM on the annual intercomparison exercises with EU laboratories for measurements collected under Art. 35-36 of the Euratom Treaty.

4.2 List of Competitive Activities

INTAMAP: The main objective of INTAMAP (Interoperability and Automated Mapping - IST Call 5: IST-2005-2.5.12, September 2006 – August 2009) is to develop an interoperable framework for real time automatic mapping of critical environmental variables by extending spatial statistical methods and employing open, web-based, data exchange and visualisation tools. To illustrate the potential of the framework of INTAMAP, a system for the automatic mapping of gamma dose rates in combination with EURDEP was developed. REM was one of the three Scientific Coordinators of the project and one of the 7 Work package leaders. During 2013 INTAMAP was integrated in the EURDEP system as additional user functionality
EURANOS IP: (FI6R-508843, April 2004 – June 2009) is a European approach to nuclear and radiological emergency management and rehabilitation strategies: The contribution of the REM group was a demonstration project on the ensemble

evaluation of long-range atmospheric dispersion forecasts from national weather and prediction sources.
Administrative Arrangement with DG JLS on "Survey of Radiological Vulnerability in the EU" (Nr. JRC.BXL.30634-2007) (see 4.1)
Annual Administrative Arrangements with DG ENER on “Support for managing data on environmental radioactivity”.
Administrative Arrangement with DG HOME on “Assessment and validation of modelling tools and decision support systems addressing CBRN releases (HOME/2010/ISEC/AA/004-A1, December 2011 – June 2014))

4.3. Mobility and training of researchers

See the above-mentioned training courses for operating the ECURIE software and the REM data submission tool for the international exchange of monitoring information.

Lecturing in the annual training course on off-site emergency preparedness and response (organised by SCK.CEN, Mol, Belgium), in which the experience with the EC information systems ECURIE and EURDEP are explained and illustrated.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2012

Action *51603 - RADMET*
Radionuclide metrology for primary standardisation and policy support
Action Leader: *Uwe Wätjen, JRC.D.4, (report prepared by Mikael Hult)*
Standards for Nuclear Safety, Security and Safeguards Unit

Authorising Officer: *Wim Mondelaers, Standards for Nuclear Safety, Security and Safeguards Unit*
Leading Institute: *Institute for Reference Materials and Measurements*

0. Policy Area

Policy theme 5 – The EURATOM programme

Agenda 5.1 –Nuclear waste management and environmental impact

Sub-agenda N° & Title: 5.1.6 Measurement of Radioactivity in the environment

1. Rationale of the Action:

International events have highlighted the needs to develop and implement highest standards for nuclear safety and security in order to ensure optimum safety of the population. This action focuses on supporting the Commission as well as the Member States in the fields of radioactivity in the environment and radiological protection, and with decay data needed for a wide range of fields with priorities given to radioactive waste management and nuclear medicine. The action will contribute intensively to standardising and harmonising measurements in these fields, to disseminating information and providing training for professionals and young scientists. Increased emphasis is given to the provision of advice to services of the Commission, Member States or external authorities through the EEAS, in the fields of expertise of this action within nuclear safety and security, in particular on radioactivity in the environment, foodstuffs and water, as exemplified in the action's response to the post-Fukushima crisis management. In this context, the action has established a reference centre for radioactivity measurements in the environment and food.

Reliable and accurate decay data like those provided by the JRC-IRMM are required for the implementation of sound nuclear waste management strategies. Their definition to good accuracy provides the means of assessing with higher reliability the variation with time of radionuclide concentrations in storage facilities, a pre-requisite for safe mid- and long-term management of wastes. The priorities for new measurements are determined in co-operation with international organisations, in particular the Nuclear Data Section of the International Atomic Energy Agency (IAEA), the Consultative Committee for Standards of Ionizing Radiations (CCRI) of the International Committee for Weights and Measures (CIPM), and the international Decay Data Evaluation Project (DDEP).

Reference measurements are also needed in support of monitoring radioactivity in the environment and in foodstuffs as regulated by Articles 35 and 36 of the Euratom Treaty, further specified in Commission Recommendation 2000/473/Euratom on the monitoring of radioactivity levels in the environment for the purpose of assessing the exposure of the population as a whole. The Council Directive 98/83/EC lays down criteria for the quality of water intended for human consumption, further specified in the Commission proposal for a Council Directive COM(2012)147final on requirements for the protection of the public health with regard to radioactive substances in (drinking) water. The Council Regulation 87/3954/Euratom (together with Council Regulations 733/2008/EC and 1048/2009/EC on imports) sets the maximum permitted levels of radioactive contamination of foodstuffs. Accurate measurements are a basis for taking undisputable decisions on radiological protection. Therefore, the Directorate-General for Energy has entrusted JRC-IRMM with the organisation of interlaboratory comparisons, as laid down in the Memorandum of Understanding No.JRC.BXL.30897 between DG ENER and JRC. JRC-IRMM gives DG ENER.D.4 the means to assess the comparability of the

regularly reported monitoring data, while it provides EU monitoring laboratories with a tool to benchmark their performance and to improve their measurement capability.

Providing training in the nuclear safety field is the answer of the action to the need for skills in the nuclear field as expressed in the flagship initiatives of Youth on the Move and the Innovation Union (COM(2010)2020). In this context, the action is also actively contributing to the European Nuclear Safety and Security School.

In summary one can say that as radioactivity is present everywhere, the work performed in this action affects every part of society. Realising the unit Bq, improving measurement techniques and performing standardisations are key activities. Although the work is focussed on certain key policy areas governed by the work programme, the impact of the work is more far-stretching and reaches into many other fields as e.g. fundamental physics, oceanography, global warming studies and radioecology just to mention a few.

2. History and development of the Action:

The Radionuclide Metrology Sector was the first operational Sector of the JRC in 1959. Its mandate was governed by the Euratom Treaty. A key task was to develop methods for measuring radionuclides with high precision and accuracy. The main objectives have changed with the JRC policy but the legacy of the early days is vivid as there is an "armada" of unique instruments available[4], which makes the Action perfectly adopted to address issues in any field where reference radioactivity measurements are needed. Starting with FP6, the action has used its extensive experience in primary and secondary standardisation of radionuclides to support EU policies, namely – on request of Directorate-General for Energy and Transport (DG TREN) – with the development and organisation of interlaboratory comparisons answering to the requirements of Euratom Treaty Articles 35/36 and related Council Directives and Commission Recommendations. This widening of focus of the action has been successfully continued during FP7 to develop support projects also in other policy areas, jointly with other actions and units of the institute or other JRC institutes. With these policy support projects the action is not only reaching out to the EC customer DGs but also to national regulatory authorities, ministries, and authorised laboratories, within the following mandates under the EURATOM Treaty (Articles 35/36).

- Commission Recommendation 2000/473/Euratom on the monitoring of radioactivity levels in the environment for the purpose of assessing the exposure of the population as a whole
- Council Directive 98/83/EC lays down criteria for the quality of water intended for human consumption
- Council Directive 2013/51/EURATOM on requirements for the protection of the public health with regard to radioactive substances in (drinking) water intended for human consumption.
- Council Regulation 87/3954/Euratom sets the maximum permitted levels of radioactive contamination of foodstuffs

[4] There are about 3000 radionuclides and each decays in a different way. Therefore it is important to have many different types of detectors available for reference measurements.

- Council Regulations 733/2008/EC and 1048/2009/EC on imports of foodstuffs
- Memorandum of Understanding No.JRC.BXL.30897 between DG TREN (later ENER) and JRC on the supply of scientific and technical support on nuclear safety, waste management, radiation protection and sustainability of nuclear energy. Annex 1: … Assistance on the assessment of technical and design dossiers … in particular related to radionuclide metrology, radionuclide reference materials for inter-comparisons and organisation of such exercises, …
- Annual ENER-JRC worksheets on activities to be implemented in the framework of the Memorandum of Understanding.

In July 2009 two administrative arrangements were signed – with the EC Delegation to Turkey on behalf of DG for Enlargement (ELARG) and with DG for Justice, Freedom and Security (JLS) – for projects, which were funded during the second half of the FP7. Based on the action's experience and reputation in radionuclide metrology, it was requested to provide technical assistance in policy support areas, where there is a need for reliable, independent and credible reference measurements or for training in the field of nuclear metrology.

MANDATES

In addition to what has been stated Chapters 1 and 2:

Administrative Arrangement with DG JLS JRC-JRC.BXL.AA.31350-2009 "Illicit Trafficking Detection Assessment Program: ITRAP+10".

Administrative Arrangement with DG ELARG TR0802.09 "Improving Chemical and Ionising Radiation Metrology" in the frame of the European Union Instrument for Pre-accession Assistance (IPA) – EMIT (Europe and Metrology in Turkey).

Memorandum of Understanding with DG TREN (ENER).

3. Description of the Action

3.1. Clients and Stakeholders

- DG TREN (Energy and Transport), Unit H.4 Radiological Protection (now DG ENER-D.3) together with national nuclear or environmental regulatory authorities, ministries, competent authorities and their designated laboratories for monitoring radioactivity in the environment or food
for the field of interlaboratory comparisons under Euratom Treaty Articles 35/36.
- International organisations at the top level of the metrology structure, i.e. the Comité and Bureau International des Poids et Mesures (CIPM and BIPM) and their Consultative Committee for Ionizing Radiation (Section II: Radioactivity - CCRI(II)) together with the International Committee for Radionuclide Metrology (ICRM), the national metrology institutes and their European association EURAMET and the IAEA
for the work related to standardisation of radionuclides (harmonisation of the measurement system for radioactivity) and measurement of nuclear decay data. (DG Enterprise – now GROWTH - as indirect stakeholder)

- National metrology and nuclear research institutes in new Member States and Candidate Countries

for long- and short-term training, reference measurements and advice for strengthening ionising radiation metrology in the country (Bulgarian Institute for Nuclear Research and Nuclear Energy (INRNE) and Turkish Atomic Energy Authority (TAEK)). (DG Enlargement as indirect stakeholder, from July 2009 also as direct client)

- National metrology institutes (NMIs) of MS (like NPL, PTB, CIEMAT, SCK•CEN, LNHB etc.)
for collaboration on training activities (VERMI schools) and development in the field of radionuclide metrology

- Belgian hospitals and local universities
for providing reference values for intercomparisons and for training and measurement support

- DG JLS (HOME)
for work on standardisation of nuclear security equipment (ITRAP+10 and ITRAP+10 Phase II)

- DG SANCO (SANTE)
for work on standardisation of techniques for measuring radioactivity in food and feed.

- Oceanographic Society of Japan
for supportive work in measuring radioactivity from Fukushima in the Northern Pacific.

- Hiroshima University and Radiation Effects Research Foundation
for supportive work in measuring radioactivity from Hiroshima.

- IAEA and international NMIs like NIST, KRISS and NMIJ
for support in certification of radioactive reference materials.

- ERNCIP (European Reference Network for Critical Infrastructure Protection)
for providing expertise in digital data acquisition and propose new standards.

- International Standardisation bodies, mainly IEC, CEN (TC391) and CENELEC
for standardisation of radiation detectors and instruments relevant for nuclear security and illicit trafficking.

3.2. Major Objectives, deliverables and impacts

Note that the objectives may have different numbers in the seven different work programmes 2007-2013 as the objectives were updated each year. When the number (#) is different in any of the other WPs (from 2010) it is given within brackets. Contributions to EMRP were in some work programmes explicitly mentioned as objectives. For the sake of clarity, and as the EMRPs adhere closely to the work programme anyhow, (a selection of) their deliverables have been introduced under the different general objectives in this compilation.

Objective 1: To prepare and organise international comparisons of radioactivity measurement in environmental matrices in order to evaluate comparability of data provided by Member States according to Articles 35 and 36 of the Euratom Treaty. Accredited according to ISO 17043. (#3, 2011)

Deliverables:

- Evaluation report of EC measurement comparison on the determination of Ra-226, Ra-228, U-234 and U-238 in mineral waters.

- Evaluation report of EC laboratory comparison on the determination of natural and anthropogenic radionuclides in soil.

- Evaluation report of EC laboratory comparison on K-40, Sr-90 and Cs-137 in dried bilberry powder.

- Radiochemical characterisation of mineral waters for a European interlaboratory comparison (Evaluation report on the comparison pending).

- Preparation and characterisation of a Dried Bilberry Powder Certified Reference Material (CRM).

- Workshop for comparison participants, giving full account of the determination of the SIR-traceable reference values by IRMM and providing results on member state laboratory performances in the comparisons on soil and mineral waters, and offering a platform for critical in-depth discussions of ways to improve radioactivity determination in the laboratories.

- Organisation together with DG TREN of the Article 35 Experts Meeting in October 2013.

Impacts:

Action's work enables the monitoring of existing and implementation of new legislation:
IRMM's support by conducting international measurement comparisons - having reference values traceable to the SI unit - allows DG TREN to fulfil its tasks of verifying the efficient and reliable operation of the monitoring laboratories in the Member States as stipulated in Euratom Treaty Art. 35. This leads to accurate and comparable monitoring results, reported to and published by the Commission (through JRC-IES) at regular intervals.

The sample types under study, organisation and results of measurement comparisons are regularly reviewed by the representatives of the Member States in the Art.35-36 meetings organised by DG TREN. Being independent of Member State interests, and at the same time member of the metrology system of BIPM and CCRI(II) for radioactivity, the action has the necessary scientific credentials and political independence to provide these measurement comparisons on behalf of DG TREN.

With a view to the forthcoming refinement of the European legislation on the quality of drinking water supplies, which will require monitoring more individual radionuclides than at present and at low levels of activity, faster and more efficient determination methods are needed. This was also found as a consequence of the effects of the Fukushima accident.

Objective 2: To strengthen international equivalence in measurement (in implementation of Euratom Treaty Article 8) by participating in CCRI (Consultative Committee for Ionizing Radiation) key comparisons of radioactivity measurement, through consultancy to CCRI on issues of radionuclide metrology, and through research into reference measurement techniques and development of instrumentation. Accredited according to ISO 17025 flexible scope. (#3, 2010; #7, 2012)

Deliverables:

- Reports to BIPM (Bureau International des Poids et Mesures) on reference measurements of the absolute activity concentration of a Lu-177, Ho-166m and an I-129 solution with different primary standardisation methods.

- Report to the CCRI (Comité Consultatif des Rayonnements Ionisants of the Comité International des Poids et Mesures) Section II on a new method to calculate a key comparison reference value and its uncertainty in order to strengthen confidence in radioactivity measurements.

- Report to BIPM and CCRI(II) on the new conceptual design for the future Reference System of Radioactivity (SIR) based on a highly reproducible ionisation chamber, more robust than the present SIR.

- Development of analytical model for efficiency calculation of 4pi-gamma counting, a primary standardisation method for activity

- Contribution to the construction of the most radiopure radiation detector ever built, Borexino.

- Contribution to construction of the GERDA detector.

- Testing of efficiency transfer codes for gamma-ray spectrometry

- Testing of coincidence summing correction codes for gamma-ray spectrometry

- Developing a method for determining the deadlayer variation in germanium-detectors.

- Developing an optimised electrodeposition method for U-238 source preparation for alpha spectrometry

- Design and conception of an underground Compton suppression system.

Impacts

This work contributes to the harmonised international measurement system in radioactivity by running comparisons, providing reference data sets, and giving advice to international organisations (CCRI(II)). The action's work thus enables comparable measurements for implementing and monitoring the European legislation.

The activity standardisation measurements performed in the frame of key comparisons define the SI-unit Becquerel for relevant radionuclides and provide lasting reference values through the SIR (International Reference System).

The conception of an improved, robust design of a reference ionisation chamber with the potential to deploy it in various national metrology institutes world-wide and to replace the existing SIR.

The impact of the Borexino detector was highlighted in the recent extended article in Nature (doi:10.1038/nature13702). The results from solar neutrinos and geo-neutrinos have huge impact in physics. (IRMM contributed to construction of the detector, JRC46363 & 54942, but is no longer an active partner)

IRMM as one of the four leading radionuclide metrology institutions of Europe - together with LNHB (France), PTB (Germany) and NPL (UK) - is a driving force in

the improvement and extension of the reference system, making it more robust and adapted also to requirements of modern nuclear medicine.

Objective 3: To improve nuclear decay data by co-ordinating and/or contributing to projects of EURAMET (European Association of National Metrology Institutes), ICRM (International Committee for Radionuclide Metrology), VERMI (Virtual European Radionuclide Metrology Institute), DDEP (Decay Data Evaluation Project), etc. (#4, 2010, 2012; #1, 2011)

Deliverables:

- Reference measurements of the photon emission probabilities of about 100 gamma- and X-ray lines of Sb-124 and of the half-life of Sb-124.

- Reference measurements of the alpha emission probabilities in the decay of Pu-240.

- Reference measurements of the half-life of Mn-54, Cd-109, Lu-177.

- Method for the analysis of alpha spectra from thick samples for environmental and bioassay monitoring

- Correction of cross section reference values for reactions producing Ta-177 through improved gamma intensities

- Half-life of the decay with the smallest decay energy known to man (a branch in the decay of In-115)

- Within the GERDA collaboration; Improved half-life of the two-neutrino double beta decay of Ge-76 but more importantly it resulted in refuting the claim of the neutrinoless double beta decay in Ge-76 made by Klapdor-Kleingrothaus

- Improved half-life limits for certain rare decays like Eu-151 (alpha decay), Pd-110 (double-beta), Pd-102 (double-beta)

- Reference decay data (half-lives, alpha emission probabilities and energies) for nuclides used in alpha-immunotherapy: U-230, Th-226, Ra-222, Po-214, Rn-218, Ac-225, Fr-221, At-217, Bi-213, Po-213, Pb-209

- Alpha-emission probabilities of U-238; uncertainty improved by a factor 10.

Impacts for Objective 3:

The measurement of accurate decay data contribute to better nuclear modelling of improvement of the quality of nuclear measurements on a global scale.

Improved values for the half-life values, alpha emission probabilities and energies with realistic uncertainty assessments allow for more accurate dose calculations to cancer patients treated with alpha-immunotherapy.

Many radionuclides like Mn-54, Cd-109 and Sb-124 are fundamental to good measurements as they are used for calibrating equipment. Better reference values have improved calibration of gamma detectors in routine laboratories.

Errors in evaluated gamma-emission data and reference cross section data were corrected, which improves the prediction of production rates for Ta-177 by nuclear reactions.

Objective 4: To enable a practical reference system for radionuclide analysis and its applications by developing matrix reference materials, characterised for radioactive components by SI-traceable reference measurements, and by developing new and adapted measurement methods. (#2, 2010, 2012, 2013; #4, 2011)

Deliverables:

- Scientific article on radionuclides in IAEA mediterranean mussel.

- Reference measurements of IAEA reference materials Bikini atoll sediment and Pacific sediment.

- Reference measurements of 3 types of rices reference materials for KRISS (Korean Research Institute for Standards and Science), NMIJ (National Metrology Institute Japan) and Japan Society for Analytical Chemistry (JSAC)

- Reference measurements with ultra low-level gamma-ray spectrometry of samples from a novel plasma diagnostic probe, which was exposed in the TEXTOR and ASDEX Tokamaks.

- Report on determination of reference values of K-40, Sr-90 and Cs-137 in bilberries for use in an ILC.

- Article on radioactivity uptake in wheat as part of an exploratory project to study differences between organic and conventional farming.

- Preparation and characterisation of a Dried Bilberry Powder Certified Reference Material (CRM) following ISO 34 for which there is accreditation.

- Production and characterisation of 6 reference materials for radioactive waste management within the MetroRWM consortium

- Production and characterisation of 5 reference materials for metallurgical industry within the MetroMetal consortium.

Impacts:

Action's work enables the implementation and monitoring of legislation requiring measurements and is beneficial for all domains where quantitative reference parameters or thresholds of radioactivity are imposed (e.g. environment, food, water intended for human consumption, energy, health, waste management).

This work extends the fundamental international measurement system to a more practical reference system for radionuclide analysis by certifying new reference materials and developing adapted measurement methods.

The newly developed plasma diagnostics probe based on activation techniques is the only operational in-vessel system and now considered for implementation in ITER. The Korean reactor KSTAR was recently changed to be able to incide this new system.

Objective 5: To give scientific-technical and policy advice to DGs, international organisations (IAEA, CIPM) and external stakeholders such as Japanese institutions in post-Fukushima crisis management and post-Fukushima measurement support. Perform reference measurement of sea water samples from the Northern Pacific

following the Fukushima accident and to support the Hiroshima dosimetry system. (former #8; #10, 2012, #5, 2013)

Deliverables:

- Report of reference measurements of Co-60 low-level residual activity in large samples from Hiroshima (at long range from the atomic bomb explosion).

- Scientific articles and presentations of Co-60 in steel from Hiroshima

- Results of 85 measurements of samples from the Northern Pacific collected in 2011 selected for their extremely low activities.

Impacts:

The Hiroshima dosimetry system forms, combined with epidemiological studies of Hiroshima bomb survivors, the knowledge base for radiological protection. Model simulations of neutron fluence and dose distribution require verification by reference measurements of the activation of well-documented historical samples. Our new measurements solve the discrepancies between older measured values of Co-60 and values obtained from model calculations. Since 1986 (Dosimetry System 86), it is model calculations that determine the dose of the 84,000 Hiroshima victims. It is essential to validate the model. Our measurements increase the robustness of the present dosimetry system (DS02, Dosimetry System 2002) which is the basis for ICRP recommendations and thus the legislation in radiation protection.

As a consequence of this successful work we were the only non-Japanese laboratory asked to measure Pacific sea water samples (in HADES) in support of a Japanese investigation following the Fukushima accident. The aim of these measurements were three-fold (i) to trace ocean current which is important for understanding the global climate, (ii) study uptake in the food chain and (iii) enable better estimates of the total release of radioactivity from Fukushima. Already in 2014 it is clear that our measurements have contributed to reveal a subduction of surface water down to a depth of 400 m near the international date-line. This is hugely important for understanding transport of CO_2 and nutrients to the ocean interior and to make better models for global warming.

Objective 6: To support the enlargement and integration policy by giving relevant training to staff of national metrology and nuclear research institutes in new Member States and Candidate Countries and to provide knowledge transfer and training. (#9, 2010; #10, 2011; #8&9, 2012)

Deliverables:

- Long-term Training (6 to 12 months) of 8 Turkish staff members from TAEK within the EMIT project.

- Contribution to 12 training courses within the EMIT project.

- Training course on gamma-ray spectrometry (4 days) held in Belgrade for 40 participants (JRC E&I action)

- Eight 2-week training courses an two 1-week advanced training courses on radiochemistry held in Ljubljana (JRC E&I action)

- Support to Euratom nuclear safety and security school

- Training opportunities for 20 persons from acceding countries during the ICRM'13 conference in Antwerp (JRC E&I action)

Impacts:

Action's work enables the implementation of the "acquis communautaire" in Turkey as far as radiological protection and free movement of goods are concerned. The training courses contributed to building scientific know-how at TAEK, Turkish Universities and staff from laboratories in acceding countries.

Objective 7: To standardise calibration instrumentation and testing methods for nuclear security-relevant equipment. (Under IRMM WP objective 1), (#7, 2010, 2011; #3, 2012, 2013).

Deliverables:

- Design, conception and providing a detailed manual of a device to irradiate nuclear security instruments under carefully controlled conditions with either neutrons or photons.

- Production and delivery of 6 items of "the irradiator" for JRC (Ispra), US DoE and US DHS.

- Establishment of a Category A liaison by a member of the Action A for JRC (requested by DG) with IEC SC45B, participation in the review process of IEC standards on testing of radiation detection equipment relevant to (nuclear) security;

- Report on use of a digital data acquisition system for nuclear security and safeguards application of a liquid scintillator

- Contribution to the ERNCIP Thematic group on radiological and nuclear threats to critical infrastructure

Impacts:

The irradiator enabled for the first time proper testing of nuclear security instruments. As no instrument adhered to the standards it highlighted the need to both adopt the standards and to improve the nuclear security instruments.
The successful execution of the ITRAP+10 led to a new AA with DG HOME, ITRAP+10 Phase II where our involved is (i) leading WP 4, to study the integration of RN and E detection techniques, (ii) leading WP5, to ascertain that the findings from the ITRAP+10 project reach IEC and are implemented in new revisions of standards for performance test of equipment against illicit trafficking.

3.3. Major Highlight(s)

1) As requested by DG TREN and the Euratom Article 35 expert group a REM (Radioactivity Environmental Monitoring) proficiency testing (PT) was organised in 2011 on K-40, Sr-90 and Cs-137 in bilberries. This was followed in 2012 by a PT on gross-alpha and gross-beta activity in drinking water. Both PTs were very successfully organised. However, due to the huge spread of results in the latter PT (gross-□□□) one can argue that the impact of it was much greater compared to the former. Three different types of drinking water were prepared and both gross-alpha and gross-beta activities had to be reported. The results were rather similar for all 6 cases, i.e. a spread of more than 3 orders of magnitude between lowest and highest value (a factor of 5000 in the worst case) and a majority of laboratories failing to

obtain acceptable values. The workshop organised at IRMM for the PT participants was much appreciated as it highlighted potential problems when performing these types of measurements. The results also triggered a discussion at the Article 35 experts meeting that DG TREN and IRMM jointly organised in October 2013. Austria has been the only MS deciding to abandon gross measurement techniques in their environmental monitoring scheme and use spectrometric techniques instead, but many MS consider this still too expensive. This highlights the training needs for gross-type of measurements.
2) Solving the so-called "Hiroshima enigma". The RERF (Radiation Effects Research Foundation) makes regular re-assessments of the health of 84,000 Hiroshima victims (e.g. PUBSY: JRC56541 & JRC61070). It is an important ongoing work to obtain better dose-estimates for each victim. Nowadays, computer calculations define the dose but they need to be validated using measurements of activation products. For 20 years there was a discrepancy between model calculations and measurements for Co-60 produced by the A-bomb in steel-structures. By performing measurements of Hiroshima steel, we could show that older measurements were incorrect and thereby showing that the present model from the DS02-report (Dosimetry System 2002) was correct (ARES 2011-1027010). This gives greater confidence in the legislation for radiation protection which is to a large extent based on follow-ups of 84,000 Hiroshima victims.
3) Training: During FP7 the RADMET action increased significantly, compared to earlier times, the amount of training courses that it organised and contributed to. Only within the EMIT project (Europe and Metrology in Turkey) 12 courses were organised and contributions given at a few more. Furthermore, several courses have been given within the JRC enlargement & Integration Action and the Euratom nuclear safety and security school.

4) There are great advancements made in nuclear medicine but the use of "new" radionuclides tailor-made for treating specific cancer forms require exact knowledge of decay parameters. Particularly half-lives, alpha emission probabilities and energies for nuclides used in alpha-immunotherapy are very important: U-230, Th-226, Ra-222, Po-214, Rn-218 have been measured. The greatest feat was to measure the decay series Ac-225, Fr-221, At-217, Bi-213, Po-213, Pb-209 with several very short-lived radionuclides that required innovative measures.
5) In 2013, work was conducted jointly with NPL and Action 53102 on uncertainty propagation in nuclear forensics. The paper (submitted in November 2013) was the outstanding most downloaded article in Applied Radiation and Isotopes (about 500 articles per year) in 2014. This is a reference paper which will strongly influence development of nuclear forensics.
6) (Official JRC impact in 2013) In May 2013, the CCRI(II) at BIPM adopted the power-moderated mean (proposed and developed by Pommé at IRMM, PYBSY: JRC71285) as the method for calculating the key-comparison reference value. This is the core of the international harmonisation as it is this value that realises global equivalence for each radionuclide. It is noteworthy that it is the first time that CCRI(II) changes its methodology and uses a weighted mean instead of a non-weighted mean, which is a politically sensitive issue.

4. Further Information

4.1. Integration and Networking

Integration within IRMM:

- with actions 51401 and 51402 of the Neutron Physics Unit (now SN3S unit) on neutron cross-section determination with low-level gamma-spectrometry *(this action 51603 was part of the Isotope Measurements Unit until 30 June 2009)*.
- with the Reference Materials Unit (changed name to SID-Unit) on the development of a CRM for radionuclide activity concentration.
- with the action 53102 (METRO) on safeguards related issues an on mass spectrometry of specific radionuclide solutions.

Integration within JRC:

- with action 51601 “REM” of JRC-IES (now ITU) for work related to interlaboratory comparisons, reporting on the status of environmental radioactivity in the EU, and harmonization of monitoring methods for environmental radioactivity.
- with nuclear security of JRC-IPSC (now ITU) preparing for a project in support of DG JLS to test radiation portal monitors against illicit trafficking. (To be funded during the second half of FP7 – see above.)
- with ITU and Ispra (Morgenstern et al.) for cyclotron-production of specific radionuclides.

Networking:

- Action leader was elected (in September 2008) Vice-President of the International Committee for Radionuclide Metrology (ICRM) and later in 2013 he became the ICRM secretary.
- Two staff members are ICRM Working Group Leaders (for Low-level Measurements and for Alpha Spectrometry)
- Action Leader is a member of the Consultative Committee for Ionising Radiation - Section II/Radioactivity (CCRI(II)), based on formal vote at the CIPM (Comité International des Poids et Mesures) of the Metre Convention.
- Three action staff members hold positions in five CCRI(II) working groups, based on formal vote in the CCRI(II).
- Action leader is also delegate member of IRMM to the EURAMET Technical Committees Ionising Radiation and Interdisciplinary Metrology.
- A staff member of the action is (since November 2008) on the International Advisory Panel to the AARM (Acquisition and Assay of Radiopure Materials) group of DUSEL, the US Deep Underground Science and Engineering Laboratory (under the NSF Major Research and Equipment Facilities Construction process).
- The action is member of CELLAR, the Collaboration of European Low-level underground Laboratories.
- The action is member of VERMI, the Virtual European Radionuclide Metrology Institute.
- The action leader is observer to the expert groups, meeting at DG TREN according to Article 31 and Articles 35 and 36 of the Euratom Treaty.
- The many EMRP projects (MetroFission, MetroMetal, MetroRWM and MetroNORM conducted in FP7; MetroDecom and MetroERM were successful applications that were made in 2013) have increased significantly the interaction with stakeholders (European industry for scrap, metal, waste management, NORM etc.) as well as with the partners that are the National Metrological Institutes.

4.2 List of Competitive Activities

MetroFission, "Metrology for new generation nuclear fission power plants", an EMRP (European Metrology Research Project administered by EURAMET. This project will develop the necessary infrastructure to enable measurement of the parameters associated with new generation nuclear power plants, in the area of materials, temperature, neutron fluence, nuclear data and radiometric methods to ensure that energy suppliers and regulators can work towards an energy secure future within a metrology framework. IRMM contributed to developments in alpha-particle spectrometry and improved decay data (half-life and emission probabilities) for U-238.
(April 2010 - April 2013)

MetroMetal, "Metrology for European Metallurgical Industry", an EMRP (European Metrology Research Project administered by EURAMET (171 k€). Today more than 50% of all steel is recycled. Generally speaking, our society needs to recycle more of all metals in order to have a sustainable society in a world with eventually a stable population of 11 to 12 billion people. Setting up systems for robust monitoring for radioactivity is an essential. This project aims at developing radioactive reference materials suitable for metallurgical industry and to design standardised measurement stations. IRMM is contributing by characterising reference materials, organising all (5) intercomparisons and contributing to the design of a standard measurement station for the metallurgical industry.
(Dec 2011 - Dec 2014)

MetroRWM, "Metrology for Radioactive Waste Management" an EMRP (European Metrology Research Project administered by EURAMET (231 k€). As many old nuclear installations need to be decommissioned there are millions of tonnes of materials (concrete, steel, light materials) that have to be controlled in a free release measurement facility. One key task or IRMM is to develop large (Europallet-sized) calibration standards for such a facility. Another important task is to improve decay data for some radionuclides for which the half-life is not known with sufficient precision for model calculations.
(Sept 2011 - Sept 2014)

MetroNORM, "Metrology for processing materials with high natural activity", an EMRP (European Metrology Research Project administered by EURAMET (776 k€). All industries dealing with thousands of tonnes of raw materials (metal extraction, water purification, fertilizer, oil&gas etc.) produce as by-product materials with enhanced levels of natural radioactivity. As these radionuclides half very long half-lives one cannot wait for them to decay (like nuclear waste) the only way to get rid of them is to dilute them in a careful way and reintroduce them in nature. This calls for improved metrological approaches and new standards which are highlighted in the new basic safety standards from the European Commission. IRMM will work on developing new reference materials, improve decay data and produce standards.
(Sept 2013- Sept 2016).

During FP7 there were also some 3rd party work carried out e.g. for plasma physics laboratory in Brussels (all the fusion related work).

During 2013 successful applications for competitive activities were performed for the following projects: **(i) MetroDECOM** – Metrology for Decommissioning of nuclear facilities. EMRP funded #ENV54 with budget of (92 k€). **(ii) MetroERM** – Metrology for Early warning Radiological Monitoring networks. EMRP funded #ENV57 (340 k€). **(iii) CEN Mandate 523** on standards for I-131, Cs-134 and Cs-137 in animal feed (125 k€)

4.3. Mobility and training of researchers

One successful PhD study:

- "Analytical methods for the determination of radionuclides in environmental samples", defended at University of Bucharest in 2010.

Several post-docs:

- work in support of the interlaboratory comparison programme for environmental radioactivity.
- work on instrumental aspects and in several applications of low-level gamma-ray spectrometry.
- work on instrumental aspects and in several applications of low-level gamma-ray spectrometry.
- with work on instrumental aspects and in several applications of low-level gamma-ray spectrometry.
- Primary standardisation of radionuclides
- Organisation of InterLaboratory Comparisons and Proficiency Testing.
- Liquid Scintillation Counting Techniques
- Preparations for the European Reference Laboratory for Radioactivity in Food, Feed and Water
- Development of a new instrument for realising international equivalence and preforming primary standardisation
- Working on the EMRP projects MetroMetal and MetroRWM.
- Organising and preparing ILCs for DG ENER.

Other:

4.4. Contributions to innovation

- In collaboration with Action 51401 there was a continued development of the technique for neutron fluence spectrometry using disk activation (DONA). It is a passive and rugged system that is applicable at low (environmental) levels of neutron fluence, e.g. in nuclear medicine departments housing an accelerator and around nuclear installations. It is potentially very useful in emergency situations as the detector (metal discs) can be dropped from helicopters and be placed in remote places for a posteriori analysis to obtain a retrospective understanding for the event (similar to what happened in an uncontrolled way at the JCO accident in 1999 and for Hiroshima dosimetry).
- Also in collaboration with the 51401 Action, a technique for measuring the neutron cross section activation curve for fast neutrons using metal disk activation (NAXSUN) was developed. Cross sections for fast neutrons are traditionally measured point wise. This technique has similarities with the DONA technique in the sense that metal discs are activated and the result (cross-section curve in this case) is calculated using deconvolution technique.

- Design and construction of a new type of TDCR (Triple-to-Double Coincidence Ratio) Liquid Scintillation Spectrometer.
- Continued development of a probe for monitoring charged particles escaping from a thermonuclear fusion plasma. Our results (from JET, TEXTOR and ASDEX) have led to change in design of the KSTAR reactor in Korea and that discussion for introducing activation probes in ITER has started.
- Development of methods for characterising germanium detectors to be employed in the GERDA double beta decay experiment (see e.g. JRC80097 and JRC 80162). This has spin-off in all fields employing germanium detectors.
- Recent key developments of reference character are (i) The PomPlots (JRC38011) - a new and intuitive way of presenting intercomparison data is beginning to show impact, (ii) The Power Moderated Mean – (see highlight above) adopted by CCRI(II) for calculating key comparison reference values, (iii) exact solutions for calculating uncertainties in radioactive dating.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2011

Action *51604 ANTE*
Analysis of Nuclear Traces in the Environment
Action Leader: *Erich Hrnecek, E.07*

Authorising Officer: *Jean-Paul Glatz, E.05*
Leading Institute: *Institute for Transuranium Elements (ITU)*

0. Policy Area

Policy theme 5. The EURATOM programme
Agenda 5.1 Nuclear waste management and environmental impact
Sub-Agenda 5.1.6 Measurement of radioactivity in the environment

1. Rationale of the Action:

Chapter 3, Title II of the EURATOM treaty constitutes the establishment of basic safety standards for the protection of workers and the general public against the dangers arising from ionizing radiations. Articles 31 to 38 describe the implementation of this task by the European Commission with regard to the protection of human health, the control of emission of radioactivity into the environment and nuclear waste management. According to Article 39, JRC provides assistance to the Commission in carrying out this assignment.
Within this frame, there is an increasing demand for fast and reliable analytical methods for the determination of radionuclides in the environment and the development and validation of such advanced analytical methods is necessary to ensure an independent verification of the quantity and origin of environmental radioactivity. The JRC competence in bulk and particle analysis is used to develop projects and cooperation for the determination of radioactivity in the environment; including assistance in radiological emergencies.

2. History and development of the Action:

Started 2009 as follow-up of the MARE action, finished in 2011.

3. Description of the Action

The objectives of this action are to further develop and provide assessed methods for the analysis of traces of radioactive and nuclear materials in the environment. The action is focusing on providing a better determination of the origin and sources of man-made radionuclides in the environment and a better comprehension of the mechanisms connected to their environmental impact. Upon request by Member States authorities, the action, in coordination and complementarity with other JRC's environmental actions, aims to provide support by offering a range of expertise and experimental tools for characterizing radioactivity in environmental bulk and particle samples.

3.1. Clients and Stakeholders

Customer/users (outside the European Commission)
Environmental Agencies in EU member states
Industry
IAEA Marine Environment Laboratories

Customer DGs (inside the European Commission):
Energy and Transport

Keywords: Environmental radioactivity, nuclear discharges, radiation protection, trace analysis

3.2. Major Objectives, deliverables and impacts

• **Objective 1:**

Providing expertise on environmental monitoring and measurement methods on request of DG customers in support of their policy.

 Upon request by administrative arrangement, support to DG ENERGY by participation in verification visits of environmental monitoring facilities under the terms of Article 35 of the Euratom Treaty. Support in preparation of verification visit reports.

Policy 1.2.1 Safety of Nuclear Fuel Cycle / Nuclear Waste

Funding: Administrative Arrangements

Customers DG ENER - Energy

• **Objective 2:**

Providing expertise on environmental monitoring and measurement methods on request of international and Member States organisations in support to their policy. The main contributions will focus on research and training activities on radioactivity in the environment, in collaboration with IAEA-Environmental Laboratories (joint collaboration agreement signed in 2009) and on a joint project with the Nuclear Research Center Negev (NRCN) on analysis of environmental Uranium particles, within a collaboration agreement between JRC and the Israel Atomic Energy Commission (IAEC).

Collaboration with IAEA-EL involving specialized measurements on environmental radioactivity. Measurements and reports.

Funding: Institutional

Customers IAEA-MEL - Marine Environment Laboratory of IAEA

 Collaboration with NRCN on comparison of SIMS and Laser Ablation-ICPMS measurement methods for analysis of environmental Uranium particles. Measurements and reports.

Funding: Enlargement & Integration

Customers External NRCN - Nuclear Research Centre Negev, Israel

• **Objective 3:**

Development of advanced trace analytical methods for bulk and particle samples to answer environmental samples analysis policy needs and requests. The objective involves the scientific and technical development of new techniques and their applications for customer needs. The work will focus on the improvement of methods for identification of Uranium and Plutonium and their characterization in environmental samples. Additionally, methods for analysis of radioactive samples by online chromatography coupled to ICPMS will be further developed.

 In collaboration with Vienna Environmental Research Accelerator and Institute of Environmental Geochemistry, Heidelberg, application of Accelerator Mass Spectrometry (AMS) for determination of Uranium-236 and Plutonium isotopes in peat core samples.

Funding: Exploratory Research

Customers External University of Vienna

 Development of methods for fast determination of environmental actinide traces by online chromatography coupled to ICPMS.

Funding: Exploratory Research

3.3. Major Highlight(s)

Support to DG ENER for EURATOM Art. 35 verifications.

In total, support was given by participation in 10 verification missions and co-authoring the verification reports.
See:
http://ec.europa.eu/energy/nuclear/radiation_protection/article35/article_35_en.htm

Exploratory research:
Developments to use environmental ^{236}U as tracer of nuclear activities. First determination of the ^{236}U peak from Nuclear Weapons Tests in a terrestrial environment (peat bog). Determination of pre-anthropogenic $^{236}U/^{238}U$ isotopic ratio of $(3.3 \pm 0.7) \times 10^{-12}$ in an interglacial peat sample for the first time using clean room facilities and AMS.

4. Further Information

4.1. Integration and Networking

A short description of the action “integration (JRC internal collaborations), networking (positioning within external collaborations)

Internal: actions FACIL, NWD

external collaborations

U-236 as tracer of anthropogenic nuclear activities
W. Shotyk, Institute of Environmental Geochemistry, University Heidelberg, Germany
P. Steier, Vienna Environmental Research Accelerator, VERA, University Vienna, Austria
G. Wallner, Institute of Inorganic Chemistry, University Vienna, Austria

Studies on radioactive particles
M. Eriksson, IAEA-Marine Environment Laboratories, Principality of Monaco
E. Eylish, Nuclear Research Center Negev (NRCN), Israel

4.2 List of Competitive Activities

A list and short description of the competitive activities linked to the action (2007 to mid-2009)

4.3. Mobility and training of researchers

The Terms of Reference ask about the promotion "of mobility and training of researchers (in particular in the field of nuclear safety and security)" as well as contributions to innovation within the Community.

From 2009 to 2011 the action hosted 1 trainee, 1 PhD and 2 Post-docs.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 - 2013

Action 50003 SINSAC

Support to International Nuclear Safety Activities

Action Leader: *Brian Farrar F05*

Authorising Officer: Brian FARRAR, F05

Leading Institute: Institute for Energy and Transport

0. Policy Area

Policy Theme: 5 The EURATOM programme

Agenda No & Title: 5.2 Nuclear safety

Sub-agenda No & Title: 5.2.1 Safety of nuclear installations

EU Policy Instruments:

- Instrument for Nuclear Safety Cooperation (INSC) established by Council Regulation (EURATOM) No 237/2014 of 13 December 2013; Responsible Directorate General: DG DEVCO
- Instrument for Pre-Accession Assistance (IPA) - Nuclear Safety Programme - established by Council Regulation (EC) No 1085/2006 of 17 July 2006; Responsible Directorate General: DG ELARG

1. Rationale of the Action:

Nuclear energy is an established part of the energy mix in a number of countries around the world. Despite the Fukushima accident in 2011, many of these countries are looking to expand the use of nuclear energy. Moreover, a number of countries which do not currently generate nuclear energy have manifested their interest in embarking on a nuclear power programme.

The Chernobyl accident in 1986 and the Fukushima-Daiichi accident in 2011 highlighted the global importance of nuclear safety. Such accidents can have significant health, social, environmental, economic and political consequences and history has clearly confirmed that these consequences may extend well beyond national borders and, potentially, worldwide. The promotion and enforcement of the highest standards of nuclear safety and radiation protection within the boundaries of the EU is not sufficient to ensure protection against the consequences of a nuclear accident outside the EU.

Other threats to the environment and public health are posed by the legacy of radioactively contaminated sites and radioactive wastes or disused sealed radioactive sources that are insufficiently contained, conditioned or stored. These exist in a number of countries that have operated nuclear fuel cycle facilities or undertaken research or medical activities and which have a history of poor safety culture and/or are technologically ill-equipped to deal with the issues. Many, but not all, of these countries were part of the former Soviet Union. Several countries of the Balkans also have problems with legacy wastes, sources and spent fuels that have to be addressed in order to prepare for EU accession.

The EU has a mature nuclear industry and, as a result of its lengthy experience in the field, has the capacity to cooperate with partners building or intending to build NPPs, or having to deal with the clean-up of nuclear legacies, in order to ensure that all nuclear activities are conducted in line with the highest standards of safety and security.

For these reasons the European Union is engaged in actions in countries outside the EU (EU accession and 'third countries') with the overall objectives of promoting a high level of nuclear safety and radiation protection worldwide. These actions are implemented through the following instruments:

- the Instrument for Pre-Accession Assistance (IPA), for the countries engaged in the process of accession to the EU, and
- the Instrument for Nuclear Safety Cooperation (INSC) for other 'third countries' worldwide.

The IPA and INSC programmes are implemented by DG ELARG and DG DEVCO respectively. These DGs are responsible for preparing annual programmes of nuclear safety projects to be implemented in a number of beneficiary countries, and for tendering, contracting and managing the implementation of these nuclear safety cooperation projects. The implementation of such complex technical projects requires a competent and independent technical and scientific resource to support the responsible units of these DGs for the management of the projects throughout the whole project lifecycle. Through its scientific research activities in the area of nuclear safety JRC-IET has the required nuclear safety competence, in addition to the necessary independence, to provide the required technical support.

2. History and development of the Action:

JRC-IET has been providing technical and scientific support to DGs ELARG and DEVCO (and their predecessors) for the implementation of projects for improving nuclear safety outside the EU since 1998. The EU Policy Instruments involved at that time were the PHARE and TACIS nuclear safety programmes, the beneficiaries of which were, respectively, the eastern European countries which acceded to the EU in 2004 and 2007 and the ex-Soviet countries in the Commonwealth of Independent States. The PHARE and TACIS instruments were closed at the end of 2006 and were replaced by the IPA and the INSC (having a more global perspective than the ex-Soviet Union) respectively.

JRC-IET's technical support activities in this area are financed by inter-DG contracts known as Administrative Arrangements. Initially, and for several years, these activities were 'stand-alone' and they were not associated with any JRC institutional action. From 2008, all JRC's activities were organised around institutional actions, and the activities supporting the IPA and INSC were incorporated into the Action POS (Action 52103), and later into NUSAC (Action 52104). However, as the activities were not strongly related to those of the EU Clearinghouse (NUSAC Action), it was finally decided that from the beginning of 2013 a dedicated action would be created, for the activities supporting IPA and INSC, called SINSAC (Action 50003).

Throughout all these changes in the positioning of the activities within different institutional actions of the JRC work programme, the activities themselves have remained relatively stable, employing a team of about 12-13 full-time equivalent staff throughout the whole FP7 period.

Although the SINSAC Action only existed for the last year of FP7, this report describes the activities performed in support to DGs ELARG and DEVCO for the implementation of the IPA and INSC programmes for the whole FP7period. They are therefore not described in detail in the corresponding reports for the Actions POS and NUSAC.

3. Description of the Action

The Action provides the direct technical and scientific support required by DGs ELARG and DEVCO for the implementation of the programmes and projects of the IPA and INSC. The specific activities performed are defined by the customer DGs on an ongoing basis; they are focussed on the following priority areas of the programmes:

- Support to Regulatory Authorities and Technical Support Organisations of partner countries, including the reinforcement of regulatory frameworks, in order to ensure that these organisations have the required infrastructure, technical capability and independence to enforce adherence to appropriate nuclear safety standards
- Support to NPP operating organisations aiming at safety improvements of the design, operation and maintenance of NPPs

- Support to the organisations responsible for the safe decommissioning of nuclear facilities, contaminated land remediation and management of radioactive waste, including management of nuclear materials and radioactive sources from research, medical and industrial (non-NPP) applications of ionising radiations
- Emergency preparedness (accident prevention as well as response in the event of an accident)

The activities of the IPA and INSC programmes are implemented by DGs ELARG and DEVCO through the contracting of projects which are managed centrally by the staff of these DGs. Detailed programming is performed on an annual basis through annual Action Programmes (APs) containing the projects defined jointly by the beneficiary countries' organisations and the Commission Services. The Annual Action Programmes of the INSC typically comprised 20-30 projects and had an average budget of €75 million/year, while the annual programmes of the IPA nuclear safety part (which covered only the years 2007 – 2011), typically comprised 7 – 10 projects and had an budget of around €8 – 10 million/year.

The programmed projects are implemented through competitive tendering leading to contracts with expert organisations, mainly from the EU nuclear industry. JRC experts provide the necessary technical input and support for:

- the selection and definition of projects to be included in the Annual Action Programmes,
- the development of technical tender documentation (Terms of Reference and Technical Specifications) required for tendering and contracting the projects,
- the evaluation of tenders,
- contract negotiation,
- project/contract implementation management,
- evaluation and assessment of project results
- dissemination of information on completed projects.

These activities are repeated on an annual basis, in line with the annual programming cycle. The activities are basically the same each year, but the projects for which these activities have to be performed vary significantly each year and cover a wide range of nuclear safety issues and technical topics.

3.1. Clients and Stakeholders

The Customer DGs (inside the European Commission) are:

- DG ELARG (Instrument for Pre-accession Assistance)
- DG DEVCO (Instrument for Nuclear Safety Cooperation)

The stakeholders/users (outside the European Commission) are:

- Ministries, Regulatory authorities, TSOs, nuclear operators, waste management organisations and other organisations of the nuclear sector in the partner countries benefitting from the technical cooperation projects.
- Contractors of the projects, including EU regulatory bodies, TSOs, industrial companies working in the EU nuclear sector

- IAEA (receives funding under both the IPA and the INSC for implementing projects in partner countries)

3.2. Major Objectives, deliverables and impacts

Listed below are the objectives, main deliverables and impacts registered for the SINSAC Action for 2013. The list of registered deliverables of the Action for 2013 is given in section 5.3. Similar objectives, deliverables and impacts were applicable to the activities for each year throughout the FP7 period.

Objective 1: To provide technical and scientific support for the preparation of the Instrument for Nuclear Safety Cooperation (INSC) Annual Action Programme 2013 and for the implementation of the programmes and projects of the INSC.

Main deliverables:

- Annual Report/Final Report and other administrative reporting documents on the specific Administrative Arrangement(s) between DG DEVCO and JRC for the support to the project cycle management of nuclear safety projects of the Instrument for Nuclear Safety Cooperation.
- 'Action Fiches' (documents describing the technical and administrative provisions of proposed INSC projects) for inclusion in the 2013 Annual Action Programme of the INSC. Action Fiches may be drafted by JRC or reviewed by JRC if originated by other organisations, e.g. in the beneficiary country. Only those drafted by JRC are included in the list of deliverables included in section 5.3.
- Technical Terms of Reference (ToR) for inclusion in the Tender Dossier of INSC projects (several ToRs per year depending on the content of the Annual Action Programmes and the signing of Financing Agreements with Partner countries). ToRs may be drafted by JRC or reviewed by JRC if originated by other organisations, e.g. DEVCO contractors or beneficiary country organisations. Only those drafted by JRC are included in the list of deliverables included in section 5.3.
- Review reports providing technical assessments and evaluations of INSC project results as provided in the final technical and administrative deliverables of the projects.
- Other deliverables of the activities which are not systematically recorded in the JRC publication registration system:
    - Reviews of ToRs and Technical Specifications for supply contracts prepared other organisations.
    - Reviews of INSC project administrative reports.
    - Technical opinions and ad-hoc advice to DG DEVCO on request of DEVCO Project Managers.
    - Project dissemination summaries: Summaries of the objectives, scope of work, results and achievements of completed INSC projects for uploading onto the TACIS/INSC dissemination website hosted by JRC on behalf of DG DEVCO.
    - Participation in tender evaluation committees organised by DG DEVCO for the assessment of tenders and proposal of recommended contractor.

  Including all of the above, JRC provided more than 330 deliverables to DG DEVCO in 2013 and this is typical of the annual output of the activities during the previous years of FP7.

Impacts

The Action has provided DG DEVCO with required technical inputs to successfully prepare, contract and manage its portfolio of actions in the framework of the Instrument for Nuclear safety Cooperation (INSC). Through the implementation of these actions, the EU is able to promote and directly contribute to higher levels of nuclear safety in countries outside the EU by assisting in the resolution of real, identified nuclear safety deficiencies in Beneficiary countries, while ensuring sustainability by increasing the strength, technical capacity and safety culture of the entities involved in nuclear activities in those countries. The actions encompass a broad range of activities in many different fields such as capacity building of nuclear regulatory bodies, operational safety of nuclear power plants and other nuclear facilities, radioactive waste management, decommissioning and remediation of contaminated sites.

Objective 2: To provide technical and scientific support for the implementation of the programmes and projects of the nuclear safety component of the Instrument for Pre-Accession Assistance (IPA).

Main deliverables:

- Annual Report/Final Report and other administrative reporting documents on the specific Administrative Arrangement(s) between DG ELARG and JRC for the support to the implementation of the IPA projects and programmes in the European Accession countries.
- Technical Terms of Reference for inclusion in the Tender Dossier of an IPA project (one or more ToRs per year depending on the content of the Annual Action Programmes).
- Review reports providing technical assessments and evaluations of IPA project results as provided in the final technical and administrative deliverables of the projects.
- Other deliverables of the activities which are not systematically recorded in the JRC publication registration system:
    - Reviews of Technical Specifications for supply contracts prepared other organisations.
    - Reviews of IPA project administrative reports.
    - Technical opinions and ad-hoc advice to DG ELARG on request of ELARG Project Managers.
    - Participation in tender evaluation committees organised by DG ELARG for the assessment of tenders and proposal of recommended contractor.

Including all of the above, JRC provided more than 50 deliverables to DG ELARG in 2013 and this is typical of the annual output of the activities during the previous years of FP7.

Impacts

The Action has provided DG ELARG with required technical inputs to successfully prepare, contract and manage its portfolio of actions in the framework of the Instrument for Pre-accession Assistance (IPA). Through the implementation of these actions, the EU is able to promote and directly contribute to higher levels of nuclear safety in countries in the process of accession to the EU by assisting in the resolution of real, identified nuclear safety deficiencies in those countries, while ensuring sustainability by increasing the strength, technical capacity and safety culture of the national entities involved in nuclear activities in the countries concerned. The actions

encompass a broad range of activities in many different fields such as capacity building of nuclear regulatory bodies, operational safety of nuclear facilities, radioactive waste management, decommissioning and remediation of contaminated sites.

Objective 3: To host, maintain and continuously update the databases and web sites for dissemination of information on completed projects of the TACIS Nuclear Safety and INSC Programmes.

Main deliverables:

- Technical note on the operation, maintenance and further development of the database and web site for dissemination of information on completed projects of the TACIS Nuclear Safety and INSC Programmes.
- Monthly Progress Report of JRC activities on the Tacis/INSC Dissemination Database.

Impacts

The Action supports DG DEVCO with regard to their objectives related to public information and visibility. The TACIS/INSC Dissemination website and database contain, and disseminate to the general public, information on all implemented actions of the instruments, including basic information on the contracts (e.g. contract value, name of contractor,..), as well as detailed descriptions of the objectives, scope, results and achievements of each action.

3.3. Major Highlight(s)

- The period of FP7 coincided with the period of the new INSC which replaced the TACIS nuclear safety programme after 2006. During the period, JRC successfully supported DG DEVCO in the transition from the TACIS programme, which was limited to ex-Soviet countries and covered predominantly Russia, Ukraine and Armenia, to the worldwide INSC programme. By the end of the period, JRC was supporting the implementation of over 100 nuclear safety projects of the INSC in over 20 countries in Eastern European, the Middle-East, North Africa, Central Asia, South-East Asia and the Far East.
- From 2008 to 2010, in the framework of the Memorandum of Understanding on cooperation in the field of energy between the European Union and Ukraine, the European Commission financed a major project to evaluate the safety of Ukrainian nuclear power plants, the so-called EC-IAEA-Ukraine Joint Project. DG DEVCO contracted the IAEA to organise the evaluation and requested JRC-IET to contribute to the development of the evaluation methodologies and participate in the technical evaluations. These evaluations consisted of Design Safety Review Missions and Operational Safety Review (OSART) Missions covering each of the 15 operational NPP units, Radioactive Waste Management Safety Review Missions to each of the four NPP sites and one Integrated Regulatory Review Service (IRRS) Mission to the Ukrainian Regulatory Authority. JRC-IET provided an expert to participate in all review missions. The project completed successfully, on time and the final report was issued in February 2010.

4. Further Information

4.1. Integration and Networking

As part of its work in this action, JRC is deeply involved in EC competitive tendering procedures, including the technical specification of project scope / content, the evaluation of tenders and recommendations for contracting. For this reason, neutrality and independence from any commercial interests or organisations is essential for the proper discharge of the work. To ensure that this is the case, the work is carried out almost exclusively by permanent staff and the action is not involved in any networks or collaborations.

4.2 List of Competitive Activities

All the activities performed in the framework of this action are competitive activities. The list of contracts (Administrative Arrangements) signed to cover the related activities during the period of FP7 is given below:

DG DEVCO:

Acronym	Topic	Duration	Income (EUR)
TAREG 01/04	Joint Research Centre - Support to the project cycle management of TACIS projects	04/01/2007-02/01/2011 4 years	2 000 000
TAREG 01/05	Joint Research Centre - Support to the project cycle management of projects in the sector of nuclear safety	29/02/2008-27/02/2013 5 years	2 500 000
TAREG 01/09	Technical Support to the project cycle management of nuclear safety projects (JRC)	12/11/2009-11/11/2013 4 years	2 500 000
TAREG 01/11	Technical Support by the Joint Research Centre for the project cycle management of nuclear safety projects	19/12/2012-18/12/2015 3 years	2 500 000

DG ELARG:

Acronym	Topic	Duration	Income (EUR)
PHARE/IPA 2006	Technical back-up to PHARE/IPA nuclear activities	02/10/2007-31/03/2010 30 months	279 000
PHARE/IPA 2010	Technical back-up to the PHARE/IPA horizontal programme on nuclear safety and radiation protection	31/03/2010-28/02/2013 35 months	314 000

IPA VINCA	Monitoring of projects at the Vinca site	27/03/2013-26/03/2015 2 years	399 719
PHARE/IPA 2013	Technical back-up to IPA as part of the 2011 IPA horizontal programme on nuclear safety and radiation protection	24/05/2013-23/05/2015 2 years	355 000

4.3. Mobility and training of researchers

As mentioned in 4.1, the action does not host short-term visiting experts or temporary staff.

The involved JRC personnel rely on their nuclear safety experience, knowledge and expertise to perform these activities and it is therefore essential for the action that JRC can recruit experienced personnel with a high level of skills and knowledge acquired in the nuclear energy sector. Nevertheless, due to the wide spectrum of technical subjects covered by the INSC and IPA projects, a significant amount of desktop research is also required to carry out the duties. This allows the experts involved, and the team as a whole, to continuously update and broaden its skills, know-how and knowledge base over a wide range of topical nuclear safety issues. Evaluation of tenders from expert nuclear organisations, as well as review of technical deliverables of the projects, also adds to this competence building aspect of the INSC and IPA work.

Although there is a team of staff allocated to the Action, those staff also contribute part of their time to other related actions in the Unit, i.e. NURAM (Action 52105) and NUSAC (52104) and vice-versa.

5. Other Information

5.1. Publications, Technical Reports, Thesis

	Total
e contribution to a peer-reviewed periodical listed in the ISI SCI-exp and/or SSCI	-
Scientific and Technical Reports	35
Contributions to Policy Documents	-

EUROPEAN COMMISSION
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Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 - 2013

Action 52103 POS

Current Nuclear Reactors- Operation Safety

Action Leader: *Christiane Bruynooghe F05 (until May 15, 2011), Oliver Martin F04 (ex-F05) (interim leader May 16 – Dec 31, 2011)*

Authorising Officer: Brian FARRAR, F05

Leading Institute: Institute for Energy and Transport

0. Policy Area

Policy Theme: 5. EURATOM programme
Agenda N° & Title: 5.2 Nuclear Safety
Sub-agenda N° & Title: 5.2.3 Safety of nuclear installations

1. Rationale of the Action:

Nuclear safety of the operating installations is more and more subject to optimisation in order to meet the new challenges posed by the market liberalization and the long term operation of the plants, which has to be safe and reliable. In line with these challenges the FP7 Euratom Research Program is focused on ensuring the continued safe operation of existing nuclear power installations. Within this context research priorities have been identified identifying in the following areas: Maintenance, Testing, Surveillance and Inspection (MS&I) programs, ageing management for safety related components, thermal hydraulics analysis supporting plant improvement and modifications, engineering programmes supporting operation, plant safety assessment, operating procedures and human reliability aspects.

The optimisation of these programmes requires a large effort of development of new techniques and models. While each country has its own approach an EC action can be beneficial to these endeavours through identifying where coordination, harmonised approaches, networking and training opportunities will favour the spreading of good practices through the EU. Moreover, the development of new standards and norms for component qualification and safety assessment also suggests full coordination at the European level.

The action aims at facing both technical and organisational issues related to the safe operation of the existing European nuclear facilities providing ready-to-use, validated methods, models and recommendations for procedures.

2. History and development of the Action:

The action SONIS[5] started in 2007, within the seventh framework programme. It covered a completely new research and policy support area, never covered by any other action in the nuclear area, focussing on the operation safety of existing nuclear installations, according to the MA WP, where operation safety had a very high priority. The Action POS (52103) formally started on September 1, 2008 as a follow-up of the major re-organisation at IET (at that time the Institute for Energy (IE)). It was re-designed collecting the contributions of the former action SONIS (all tasks), AMA[6] (in relation to accident management and probabilistic safety assessment) and SAFELIFE (in relation to component ageing).

As of 2008 SONIS/POS participated in the NULIFE Network (Nuclear Plant Life Prediction) that has been launched under the EURATOM FP6 Program with a clear focus on integrating safety-oriented research on materials, structures and

[5] Safety of Operating Nuclear Installations
[6] Analysis and Management of Nuclear Accidents

systems and exploiting the results of this integration through the production of harmonised lifetime assessment methods. As of 2009 POS participated in the action SARNET2 (network on severe accident management and mitigation issues), and the EC participation to Phebus was also included in POS.

The actions SONIS and POS operated and contributed to the three important research networks ENIQ (in the area of In-service inspection (ISI)), SENUF (in the area of NPP maintenance) and APSA (in the area of time dependent probabilistic safety assessment of NPPs).

It is recognised that nuclear energy safety concerns don't stop at the EU borders and the action included since the beginning a huge contribution to operation safety of existing nuclear installations in the neighbouring countries. This is implemented through technical support to the DGs that sponsor nuclear safety enhancement projects in the candidate or CIS countries (countries emerging from the former Soviet-Union). In addition partners of these countries are closely associated to the research networks mentioned above.

In terms of development of the action objectives and continuous monitoring of the R&D action, it has to be noted that at the beginning of 2008, as a response to the PAR 2007 exercise, the policy support contribution of SONIS was strengthened furthermore and a clear identification of customer DGs, services, MS and Intl. Organisations led to a more effective policy support action, also driven by two new MoUs (DG TREN / ENER, IAEA). The Scientific Output was also drastically increased from 2008 to 2011. After the first year of the project SONIS, where only scientific publications were issued (not PAR relevant), seven peer-reviewed publications (only two PAR relevant) were issued in 2008, 34 publications (7 PAR relevant) were issued in 2009, 56 publications (with 24 PAR relevant) were issued in 2010 and 44 publications (with 20 PAR relevant) were issued in 2011.

In terms of integration with other IET actions, SONIS/POS developed important links with the action NUSAC (52104), SAFELIFE and AMA and, following the re-organisation of IET in 2008, with FANGS (Action 52302), MATTINO (Action 52304) and CAPTURE (Action 52303) in the respective fields of operational experience of NPPs (integral part of plant operation safety), ageing of materials and components, ageing effects in probabilistic safety assessment of nuclear plants, severe accidents and nuclear education and training.

The cooperation with the NUSAC action led to the development of several technical reports (authored by POS staff) with analysis of operational events and proposal for generic lessons learnt at the European Plants, as well as two topical reports well acknowledged by international organisations (IAEA, OECD). Similarly, the cooperation with AMA led to the joint management of the scientific network APSA[7], which covers special issues related to plant safety assessment. Those areas of cooperation developed in the course of 2007 and 2008 naturally led to a full integration of NULIFE and APSA into POS in the year 2009. Cooperation with FANGS enabled contributions to Phebus and the FP7 project SARNET2 from 2008 to 2011. Cooperation with MATTINO led to contributions to NULIFE activities, in particular to the NULIFE white paper on stress corrosion

[7] Ageing Probabilistic Safety Assessment

cracking (SCC) initiation and involvement & contribution to the FP7 project proposals CORINI (on SCC initiation, unsuccessful proposal of the 2011 FP7 Euratom call) and MULTIMETAL (on dissimilar metal weld integrity and toughness testing, successful proposal of the 2011 FP7 Euratom call). Cooperation with CAPTURE led to issuing of a number of e-learning modules in collaboration with IAEA on dedicated degradation mechanisms.

Participation to Phebus and SARNET were included in the POS WPs 2009-2011. Although these programmes are older, they had been included in other JRC actions before 2009. In the frame of Phebus one POS member was the representative of the EC at Cadarache on a permanent basis; the POS task related to SARNET was limited to giving sustainability to the Data Base related to severe accident experiments and modelling and this was conducted in close connection with the Action CAPTURE.

3. Description of the Action

The action is devoted to operational nuclear safety and as such supports the following DGs: DG TREN / ENER in charge of the EURATOM treaty obligations giving obligation to the MS of implementing high safety standards for their nuclear installations and in charge of assessment of energy policy in Europe; DG ELARG in charge of supporting the efforts of candidate countries toward EU-compliant nuclear safety level of their installations; DG DEVCO (at that time AIDCO) which sponsors the enhancement of nuclear safety in CIS countries, in the frame of TACIS, and other countries as well in frame of the INSC (Instrument for Nuclear Safety Cooperation) set-up in 2007 as a new instrument after TACIS completion.

3.1. Customers and Stakeholders

The Customer DGs (inside the European Commission) and their level of involvement are listed in the following:

- DG TREN / ENER - Definition of research priorities, recipient of research, consultancy and services;
- DG ELARG - Recipient of consultancy and services;
- DG AIDCO - Recipient of consultancy and services;
- DG RELEX - Recipient of consultancy and services;
- DG RTD - Recipient of consultancy and services.

The customers/users (outside the European Commission) and their level of involvement are listed in the following:

- IAEA - Coordination of research priorities, recipient of research, consultancy and services;
- OECD-NEA: recipient of research, organization and contribution to benchmark exercises.
- Members of the Network SENUF: 21 Organisations from Consultants and TSOs, Vendors, Regulators and Utilities of all the EU Countries with nuclear installations, plus Russian and Ukrainian representatives;
- Members of the Network ENIQ: representatives of Nuclear Utilities, Inspection Laboratories, Inspection Qualification Bodies;

- Members of the network APSA: 15 representatives of Nuclear Utilities, Technical Support Organisations, Universities and Research institutes;
- Members of the Network of Excellence NULIFE: Utilities, nuclear research institutes, nuclear engineering companies and universities;
- Members of the Network of Excellence SARNET 2: Utilities, Technical Support Organisations, National Regulatory Bodies, Research institutes, Engineering companies and universities;
- Members of the Contract Expert Group established by DG RTD to support the initiative of the ISTC in Russian Federation;
- Recipients of the Action NUSAC (52104).

3.2. Major Objectives, deliverables and impacts

OBJECTIVES and MEANS

(1) Support long-term EU policy needs on operational nuclear safety and security of the existing installations and optimization of the advanced nuclear energy systems (GEN III), through exploitation of the JRC competence in research in nuclear safety assessment methods and techniques. This is realized through (1) support to the programs of increasing nuclear power plants safety in the neighbouring or candidate countries (DG AIDCO, DG ENLARG) and (2) maintaining and developing ad-hoc competencies in order to efficiently support DG TREN / ENER.

(2) Provide a basis for harmonization of European best practice and approaches regarding operational safety of nuclear installations. The action addresses the operational programmes in place at the existing nuclear installations, as well as for advanced reactors, of both Western and Eastern European designs. The research includes an essential task of benchmarking of the proposed models, procedures and guidelines to real cases at real plant sites. The reactors addressed lead to concentrate on Plant Life Management (PLIM), Plant Life Extension (PLEX), qualification of in-service inspection (ISI) systems and Risk Informed ISI (RI-ISI), prevention and mitigation of accidents (SARNET, Phebus, BEPU - Best Estimate Plus Uncertainty).

(3) In developing the European Research Area, integrate the research efforts with the on-going efforts implemented by the nuclear utilities and plant designers, through development of suitable networks and collaborating with other EC bodies and international organizations.

DELIVERABLES

In terms of deliverables, a general overview is provided below. More details are provided in section 5.3.

A) Deliverables to objective 1: policy support

A-1) Policy support to DG TREN / ENER)

- Assistance in relation to Investment project notification (Article 41 of the

Euratom treaty). POS officers were invited to be part of the assessment team led by DG TREN / ENER in Bratislava (Slovenske Electrarne) and Mochovce Nuclear Power Plant (Slovakia) in relation to the Investment project notification (Mochovce 3-4 Unit, Slovakia). The technical statement provided by JRC was included as technical annex to the official position of DG TREN / ENER towards the applicant.

- A technical document (SWOT analysis - Strengths, Weaknesses, Opportunities, and Threats) was developed on comparison of operating costs among nuclear and other power production technologies for use by DG TREN.H2 in support of the development of EU Policy in the field of Energy.
- POS Officers contributed to OECD/NEA Committees (CNRA, CSNI) on behalf of DG TREN / ENER, disseminating the EU policy in the areas of concern, developing technical documents and questionnaires and co-organising an international event (Ageing Management at NPPs) in order to collect feedback on priorities and needs of the MS. Feedback on all these committees and events was transferred to DG TREN / ENER on regular basis.
- Many POS officers developed, on behalf of DG TREN / ENER, review documents on the draft IAEA Safety Guides in the field of Nuclear Safety.

A-2) Policy support to DG AIDCO, DG ELARG

From 2008, technical and scientific support to DGs ELARG and AIDCO for the implementation of the nuclear safety programmes and projects of the Instrument for Pre-accession Assistance (IPA) and the Instrument for Nuclear Safety Cooperation, respectively, were included in the POS Action until the end of 2009 (support to DG ELARG) and 2011 (support to DG AIDCO), when the activities were transferred to the NUSAC Action (Action 52104). Finally, a dedicated JRC Action called SINSAC (Action 50003) was created specifically for these activities from the beginning of 2013. A detailed description of these activities covering the whole duration of the FP7 is provided in the report on the SINSAC Action.

B) Deliverables to objective 2: harmonisation of best practices/networking

51 EUR reports were issued in POS – SONIS in the period 2007-2011, in relation to the following areas (and corresponding networks and/or projects, if applicable): Plant life management (NULIFE, SENUF), Human reliability factors, Thermal-hydraulics support to plant procedure optimization (Phebus, SARNET2), Engineering programs at nuclear plants (fire and seismic safety), Qualification of ISI including RI-ISI (ENIQ) and beyond-design basis events.

- 18 EUR Reports and 4 Technical Reports were issued in the framework of the activities of the ENIQ Network on harmonised Inspections qualification practice in Europe. In particular, 9 new Recommended Practices were issued after formal endorsement by the network. The ENIQ publications represent the only reference for ISI qualification in Europe, contributing to the harmonization of the nuclear operation practice in Europe.
- A validated plant life management model (PLIM) (including an improved maintenance optimisation model), merging economic and safety aspects in a

coordinated managerial and technical model was developed by the POS researchers including a validated set of maintenance effectiveness indicators.

- A collection of practice on human reliability factor modelling and control was carried out (and included in 3 EUR reports).
- Some proposals for fire qualification of safety related components in NPPs were developed on the basis of a thorough analysis of the challenges posed by fires to safety related structures, systems and components of NPPs (EUR report).
- Proceedings of the 6th, 7th and 8th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurised Components", held in Budapest in October 2007, Yokohama in May 2009 and in Berlin in October 2010 respectively were issued in cooperation with the US EPRI, JAPEIC and local organisers.
- 9 EUR reports related to the APSA network were issued.
- 3 EUR reports on SSC modelling and modelling of beyond-design basis events were issued.
- 11 additional EUR reports on ageing and operational aspects of NPPs were issued, mainly on ageing of specific NPP components, but also human factors.
- 3 Phebus synthesis reports were issued.

C) Deliverables to objective 3: developing European Research Area

This objective has no deliverable on its own but is realised through implementation of the tasks related to objectives 1 and 2. In these tasks workshops and networking are organised that are a strong support to dissemination of research results relevant to nuclear safety in Europe.

D) Scientific output

- 47 Scientific Papers were presented at International Conferences (ICONE, ASME/PVP, ENA, TOPSAFE, Int. NDE conference, SMiRT, NENE) and are published in the relevant proceedings.
- 53 Peer-reviewed papers were published throughout the duration of POS on all work fields of the action.
- 2 books were published with POS staff members among the authors.

3.3. Major Highlight(s)

The following highlights can be selected from the large number of R&D output described above:

- In the year 2008 POS officers were invited to be part of the assessment team led by DG TREN / ENER in Bratislava (Slovenske Electrarne) and Mochovce Nuclear Power Plant (Slovakia) in relation to the Investment project notification (Mochovce 3-4 Unit, Slovakia) pursuant to Article 41 of the Euratom treaty.

- In the year 2007, in the framework of the IET participation to the IAEA/Extra Budgetary Program on "Seismic Safety of Existing Nuclear Power Plants", and in cooperation with the JRC-IPSC, POS contributed to the development of an IAEA Safety Report on "Pre and Post-Earthquake operating actions" to be implemented at a nuclear site hit by large earthquakes. The contribution to the EBP represents one very important support to the nuclear Safety of the European operating plants after the major earthquakes occurred in Japan, fully in line with the Nuclear Safety Policy of the EU (MAWP 5.2).

- In the year 2009, as conclusion of the large effort of modelling Ageing effects in PSA, modelling was completed on real PWR PSA models. The influence of degradation effects on components into the overall plant CDF (core damage frequency) was clearly shown in general, and calculated on specific component cases.

- 9 new ENIQ recommended practices were issued. They are important guidance documents for ISI qualification, which together with the ENIQ framework documents are recognized by utilities and nuclear regulators.

- Progress in the understanding of the issue of source-term, debris coolability and fuel assembly degradation modes in the context of severe accidents within the Phebus project.

- Progress in the development and understanding of numerical models for IGSCC in metallic components and beyond-design basis events of concrete structures.

- Progress in the understanding of specific degradation mechanisms, in particular thermal fatigue and underclad cracking and detection of reactor pressure vessels.

4. Further Information

4.1. Integration and Networking

As far as necessary, collaborations with other units are set-up, mainly through participation to same competitive projects of DG RTD: SARNET, NULIFE, Phebus. Networks operated by POS were: ENIQ network on ISI qualification, SENUF network on maintenance of NPPs; APSA network (Ageing Probabilistic Safety Assessment).

4.2 List of Competitive Activities

Apart from the competitive activities performed for DG AIDCO and DG ELARG, POS participated in the following projects funded by DG RTD: NULIFE, SARNET2 and Phebus.

NULIFE, the aim of which was to help provide a better common understanding of, and information on, the factors affecting the lifetime of nuclear power plants which, together with associated management methods, will help facilitate

extensions to the safe and economic lifetime of existing nuclear power plants. In addition, NULIFE will help in the development of design criteria for future generations of nuclear power plant.

SARNET2, which was defined in order to optimize the use of the available means and to constitute a sustainable consortium in which common research programmes and a common computer tool to predict NPP behaviour during a postulated severe accident (ASTEC integral code) could be developed.

Phebus, which was a long running project with important experimental means. Its aim was to estimate the fuel assembly degradation modes, the debris coolability and the repartition of the fission products in the components outside the "core" zone (pipes and vessels). The EC representative at Cadarache was a POS member. POS was further active for writing synthesis reports of some of the experiments.

4.3. Mobility and training of researchers

POS was continuously hosting visiting scientists and short term collaborators with significant experience in NPP operation. These visits were fruitful for both sides, for POS in terms of scientific output and support and for the visiting scientist who could take advantage of the POS environment and networks.

EUROPEAN COMMISSION
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Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2013

Action 52104 NUSAC

Nuclear Safety Clearinghouse

Action Leader: Benoit ZERGER F05

Authorising Officer: Brian FARRAR

Leading Institute: Institute for Energy and Transport

0. Policy Area

1. Policy Theme: 5. EURATOM programme
2. Agenda N° & Title: 5.2 Nuclear Safety
3. Sub-agenda N° & Title: 5.2.1 Safety of nuclear installations

1. Rationale of the Action:

The effective use of Operational Experience Feedback (OEF) from Nuclear Power Plants (NPP) has been recognized as one of the challenges the nuclear industry is currently facing. NUSAC Action aims at supporting the improvement of the management of OEF in the EU participating countries, by:

- strengthening co-operation between EU licensees, regulatory authorities, TSOs and the international OE community to collect, evaluate and share NPP operational events data and apply lessons learnt.
- performing background research to support the establishment of a competence centre on OEF and nuclear safety methods and tools at the JRC,
- assessing NPP events and disseminating lessons learned to the participating countries.
- exchanging information on NPP operational events with the international OEF community.

2. History and development of the Action:

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 at Community level EU countries may benefit from pulling together their efforts to improve the operational experience feedback (OEF) process. Recognizing the importance of this safety issue and JRC capabilities, it was later requested by some EU Member States (MS) that JRC plays a central role in establishment and running of a European Clearinghouse for Operational Experience Feedback for the benefit of all MS. It was felt important to use available JRC and EU countries' expertise in the field in order to promote better cooperation, more effective use of the limited national resources of the MS and strengthening the EU capabilities for operational experience analyses and dissemination of the lessons learnt.

At the June 2006 JRC High Level Users Group meeting, the proposed action was strongly supported by DG-TREN as one of the major steps towards the further harmonization of nuclear safety practices within the EU.

Direct JRC involvement resulted in the provision of a permanent EU staff core group, with leading functions, which together with a number of representatives from interested EU Regulatory Authorities ensures the cost effective analyses and implementation of operational experience feedback to the EU countries participating in the project. The establishment of international networking between experts who are involved in OEF, as well as direct links with interested EU Regulatory Authorities

is essential.
In 2008 Regulatory Authorities from Finland, Hungary, The Netherlands, Lithuania, Romania, Slovenia and Switzerland approved Clearinghouse on NPP OEF Collaboration Arrangements and launched technical work on common operational event assessment, which resulted namely in enhanced national contribution to the IAEA/NEA International Reporting System. Several topical reports on specific operational events were produced at request of the participating countries. Regulatory Authorities from Spain and the Czech Republic joined the Clearinghouse as observers.

In April 2010, a Kick-Off meeting of the enlarged Clearinghouse was held, gathering high-level representatives of organizations already part of the Clearinghouse network and other organisations such as IAEA, OECD-NEA, IRSN, Regulatory bodies from France, United Kingdom, Germany, etc. This meeting resulted in more and more organizations joining the Clearinghouse.

As of 31.12.2013, all Regulatory Bodies from EU Member States with NPP as well as Switzerland are either members or observers of the Clearinghouse. IAEA, OECD-NEA, GRS and IRSN are also taking part in the Technical Board of the Clearinghouse.

Finally, it should be highlighted that NUSAC was the leading Action for the JRC post-Fukushima response in 2011-2012 (see below for further details).

3. Description of the Action

- Clients and Stakeholders

Member States' Nuclear Regulatory Authorities
IAEA
OECD-NEA
DG ENER
DG DEVCO
DG ELARG

- Major Objectives, deliverables and impacts

Objective 1: To improve the identification and use of lessons learned from operational experience (OE) in nuclear power plants (NPP) through the further operation and development of the European Clearinghouse on OE for NPPs.

Main deliverables:

- Multi-partner Collaboration Arrangements signed in 2008 by the Regulatory Authorities from Finland, Hungary, The Netherlands, Lithuania, Romania, Slovenia and Switzerland, creating the Clearinghouse on operational experience feedback (OEF) for nuclear power plants and launching concrete technical work on common operational event assessment. Other EU Regulatory Authorities later joined the Clearinghouse network as observers.
- Topical reports (14) about different topics such as construction and commissioning events, events related to supply chain, ageing-related events,

events related to Emergency Diesel Generators, etc.\

- Quarterly newsletter on events occurring worldwide at NPPs
- Since 2013, annual training on Root Cause Analysis and Events investigation aimed at the staff of Regulatory Authorities
- Review of event reports prepared by Regulatory Bodies for publication in the International Reporting System (33 reports reviewed)
- Web platform developed for the EU regulators participating to the project in order to improve the exchange of Operational Events Information between the network members.
- European Clearinghouse Data Base on operational experience has been developed in order to gather relevant past experience and disseminate to the EU Regulators participating to the Clearinghouse project (the database contains more than 50 000 records)

Impacts

The scientific and technical added value of the topical reports has been widely recognised by the OEF international community by publishing them on the web site of the International Reporting System, jointly operated by the IAEA and the OECD-NEA.

The scientific capacity has been progressively established by the provision of a permanent EU staff core group in the Institute for Energy and Transport, with leading functions, together with a number of representatives from interested EU Regulatory Authorities (assigned as detached national experts on a rotational principle for a fixed period) and with the use of international networking between experts who are involved in operational experience feedback such as IRSN and GRS.

The annual training on event investigation was created at the request of the Regulatory Authorities because not much training existed on this topic. The feedback on this training was very positive and it was requested to have this training each year.

Objective 2: To contribute to the EU answer to the Fukushima Daiichi nuclear accident by providing expertise and technical support.

Main deliverables:

To fulfil this objective, the following activities have been performed:

- In the direct aftermath of the Fukushima accident, the Clearinghouse published 44 so-called "Fukushima updates" distributed to different services of the European Commission, to the EU delegation in Japan and to the EU Regulatory Authorities.
- The Action has provided DG ENER with the review of the National Reports drafted in the framework of the EU stress tests for NPPs.

- The Action has provided expertise and secretariat for the implementation of the peer-reviews in the framework of the EU stress tests for NPPs
- The Action has contributed to the Staff Working Document SWD(2012)287 accompanying the communication of the European Commission to the European Council and the European Parliament on the EU stress tests COM(2012)571.
- The Action has provided DG ENER with the review of the National Action Plans drafted in response to the recommendations made in the framework of the EU stress tests for NPPs

Impacts

The impact of this activity was significant:

- The "Fukushima updates" were the only documents published on a daily basis in the direct aftermath of the accident and making the synthesis of all reliable open sources
- The practical organization of the peer-reviews was made possible thanks to the Action providing the secretariat
- The Action staff reviewing the National Reports and participating in the peer-reviews provided the technical basis for the communication of the European Commission on the stress tests

Objective 3: To further provide international organisations (IAEA, OECD-NEA) as well as DG ENER with scientific and technical support on nuclear reactor safety.

Main deliverables:

- Several technical reports and technical notes for DG ENER in support of EC viewpoint in relation to the Article 41-43 of the EURATOM Treaty.
- Technical Report for DG ENER in support of the review of national reports prepared under the Joint Convention on the Convention on Nuclear Safety
- Technical notes related to the development of standardization in nuclear safety through support to the IAEA Nuclear Safety Standard Committee (NUSSC).
- Participation to committees, working groups, initiatives and international cooperation meetings (IAEA, OECD-NEA, ...), mainly:
    - OECD-NEA: WGOE (Working Group on Operating Experience), WGRNR (Working Group on the Regulation of New Reactors), WGHOF (Working Group on Human and Organizational Factors)
    - IAEA: meeting of the National Coordinators of the International

Reporting System

Impacts

The activities in support to DG ENER allowed DG ENER to express the EC viewpoint on new build projects as well as on national reports prepared under the Convention on Nuclear Safety.

Through various working groups and committees, the Action contributed to technical reports such as the OECD-NEA reports on Fukushima precursor events, Regulatory oversight of Non-conforming, Counterfeit, Fraudulent and Suspect Items, First Construction Experience Synthesis Report (2008-2011) or to IAEA "IRS Highlights"

3.1. Major Highlight(s)

- Creation of the European Clearinghouse in 2008 and progressive enlargement over the years: all EU Regulatory Authorities of countries having NPP and Switzerland are now participating in the European Clearinghouse (17 countries). Poland joined also in 2014.
- The topical reports are recognized and now well established in the international operational experience community (for instance, the IAEA does not perform topical studies any more but publishes the Clearinghouse reports instead).
- Significant contribution to the organization and performance of the stress tests and to the technical basis of the related Communication of the European Commission.

4. Further Information

4.1. Integration and Networking

By definition, the Clearinghouse is a network of Regulatory Authorities, TSOs and international organisations and the Action is completely integrated in this network: the work plan of the Action is decided by the network and the outputs are evaluated by the network ("the clients").

This close cooperation since the Clearinghouse was created in 2008 and the quality of the outputs allowed a progressive building of recognition and trust. As an example, in 2012 the Belgian Regulatory Authority requested the Clearinghouse to participate in the international expert group in charge of providing advice on the reactor pressure vessel issue in Doel 3 and Tihange 2 NPPs.

Within JRC, the Action works very closely with other Actions of the Unit F05: in many occasions, staff of the Action worked for other Actions and vice-versa.

4.2 List of Competitive Activities

From 2010 to 2012, the NUSAC action included activities performed in support of DG ELARG for the implementation of IPA projects related to nuclear safety. In addition, during the year 2012, the NUSAC action encompassed also activities performed in support of DG DEVCO for the implementation of INSC projects. However, in order to make the reading easier and to avoid overlaps, all these competitive activities are summarized under the SINSAC Action (Action 50003) that was created later, specifically for those activities.

4.3. Mobility and training of researchers

NUSAC team is composed of a permanent EU staff small size core group, completed by representatives from interested EU Regulatory Authorities assigned as detached national experts on a rotational principle for a fixed period and additional non-permanent experts from the EU scientific community (contractual agents and grant holders). This organisation scheme enhances the mobility and training of experts in the field.

5. Other Information

5.1. Publications, Technical Reports, Thesis

	Total
Article contribution to a peer-reviewed periodical listed in the ISI SCI-exp and/or SSCI	27
JRC Scientific and Technical Reports	49
JRC Contributions to Policy Documents	6
Books	1

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 - 2013

Action 52105 NURAM

Nuclear Reactor Accident Analysis and Modelling

Action Leader: *Ghislain Pascal F05*

Authorising Officer: Brian FARRAR, F05

Leading Institute: Institute for Energy and Transport

0. Policy Area

Policy Theme: 5. EURATOM programme

Agenda N° & Title: 5.2 Nuclear Safety

Sub-agenda N° & Title: 5.2.1 Safety of nuclear installations

1. Rationale of the Action:

The lessons to be learned from the Fukushima accident will shape the nuclear energy sector for years. The Council Conclusions (EUCO 10/1/11) from 24-25 March 2011 have called for a “comprehensive and transparent risk and safety assessment” (the “Stress Tests”) of European nuclear power plants and asked the Commission to participate in this process and to “review the existing legal and regulatory framework for the safety of nuclear installations”. The IAEA Ministerial Conference on Nuclear Safety in June 2011 emphasized “the need to improve national, regional and international emergency preparedness and response to nuclear accidents” and “to strengthen cooperation among national authorities, technical safety organizations and operators, and among relevant intergovernmental and non-governmental organizations”. The ENSREG Conference on 28-29 June 2011 has pointed out the importance to further reinforce safety in the EU and in particular accident analysis and management for nuclear power plants as well as emergency preparedness of the Member States.

JRC has been already involved to different degrees in the above mentioned activities and is requested to support the policy and technical decision making which will have to be taken at EU level. It is anticipated that in the aftermath of Fukushima the need for harmonization on nuclear safety practices in Member States will be reinforced. This will result in common safety enhancement activities at EU level and in evolving EU legislation. The JRC contribution to this process, in support to policy DGs (DG ENER, DG RTD), shall be based on sound technical understanding of nuclear safety and in particular of competence in accident modelling and in the understanding of severe accident phenomena and management.

The need for JRC to establish an action to reinforce research and to build expertise on nuclear accident modelling is twofold. Better understanding of nuclear accidents enhances the optimization of the European Nuclear Emergency Preparedness and Response (Council Decision 87/600/EURATOM) at regional and European level, bringing EU added value to the national efforts and contributes to the implementation of the IAEA post Fukushima Nuclear Safety Action Plan (August 2011). At the same time the creation of an accident analysis group with modelling competence will strengthen JRC capabilities for independent assessments in the view of the post-Fukushima actions to be taken in Europe. It will help the JRC to play an active role in the review and update of the Severe Accident Management Guidelines (SAMGs) of EU NPPs in collaboration with the concerned European networks (e.g. SARNET-2 and NUGENIA) and will contribute to harmonised conclusions on best practices and guidelines for severe accident management.

2. History and development of the Action:

The Action NURAM started in 2012 and was created following a re-organisation at the Institute for Energy and Transport (IET). It was re-designed collecting part of the contributions of the former action POS (tasks related to severe accidents especially participation to SARNET and PHEBUS networks), and FANGS (in relation with modelling and safety assessment activities for Gen IV reactors).

The first year of the Action (2012) was mainly devoted to the following tasks:

- Consolidating and developing the already existing contributions through PHEBUS and SARNET networks (and through NUGENIA Association)
- Acquiring the latest versions of the necessary computer codes for Severe Accident Analyses on NPPs (ASTEC V2.0 and MAAP4.0.8)
- Recruiting new staff with expertise in the field of Severe Accident Modelling and Management
- Training all Action's staff in NPP design, accident analyses and usage of severe accident computer codes ASTEC and MAAP4
- In the field of Gen IV reactors, participation in FP7 competitive projects (ESFR, LEADER, JASMIN) on fast reactor safety assessment and on the development of a EU roadmap for safety evaluation of advanced reactor designs (SARGEN-IV) in view to evaluate the safety of innovative concepts.

Participation to PHEBUS and SARNET were included in the NURAM WP 2012. Although these programmes are older, they had been included in other JRC actions before 2012. In the frame of PHEBUS, one NURAM member was the representative of the EC at Cadarache on a permanent basis; the NURAM task related to SARNET is limited to giving sustainability to the Data Base related to severe accident experiments and modelling and this is conducted in close connection with the Action CAPTURE.

In terms of integration with other IET actions, NURAM developed important links with the action NUSAC (52104) and NURAM staff were involved in the preparation and the implementation of the EU Stress Tests in collaboration with NUSAC staff.

In 2013, NURAM continued its development to gain a deep understanding and knowledge of the computational tools acquired in 2012 and to further enhance its competence to run them and to understand, analyse and interpret the results. The work was performed in close cooperation with TSOs, especially IRSN, and initially involved the verification/validation of the latest version of the ASTEC computer code vs. JRC past experiments (FARO and STORM), followed by development and use of available models for generic reactor types for safety assessments. A large effort on staff training was continued.

Key new projects started in 2013 which reinforced NURAM contributions to the area of severe accident and especially Severe Accident Management:

- The Euratom FP7 CESAM (Code for European Severe Accident Management) started in May 2013 with duration of 4 years. The NURAM action is actively participating in several Work Packages of this project and is especially leading the WP40 focusing on Plant Applications and Accident Management for all types of EU NPPs. This project includes 19 EU and non EU partners.

- Following a request from partners (UJV Rez) the NURAM action initiated an "International benchmark on In Vessel Retention (IVR) modelling for VVER1000", this benchmark attracted immediately more than 10 key EU and non EU partners.
- The activities on Gen IV continued mainly through the work performed in the frame of GIF Working Groups and through participation in several FP7 competitive projects
    - CP-ESFR: Collaborative Project for a European Sodium Fast Reactor (1/1/2009-12/31/2012 – extended to 2013)
    - LEADER: Lead-cooled European Advanced Demonstration Reactor (4/2/2010-4/1/2013)
    - JASMIN: Joint Advanced Severe accidents Modelling and Integration for Na-cooled in Fast Neutron Reactors (12/1/2011-11/30/2015)
    - SARGEN IV: Harmonized European methodology for Safety Assessment of innovative fast reactors (1/1/2012 -13/31/2013)

Work was also extended through the support to the development of the "IAEA Comprehensive Report on Fukushima" which will be "the reference report" to be issued by the IAEA after Fukushima and to several other reports from the OECD/NEA CNRA or CSNI.

Stronger support has also been provided directly to DG ENER through the participation as member of the "Commission Task Force" for the project "Review of Current Off-Site Nuclear EP&R Arrangements in EU Member States and Neighbouring Countries“.

In terms of development of the action objectives and continuous monitoring of the R&D action, it has to be noted that right from the beginning in 2012, a large effort was made. In 2012 already 17 Policy Support Documents (PSDs) were issued and in 2013 20 PSDs. It needs to be kept in mind however that many of these PSDs are coming from reports produced in the frame of the Euratom FP7 projects to which the NURAM action participated.

The Scientific Output was also dramatically increased with 5 Peer-Reviewed Publications (PRPs) in 2012 and 11 publications issued in 2013.

3. Description of the Action

The action has the main strategic objective to provide, through an integrated reactor accident modelling, knowledge on safety and risks of nuclear reactor systems in support to the implementation of EU nuclear safety policy.

The main target of this action is to support DG ENER in the field of Severe Accident and Emergency Plan and Response. This action was sustaining JRC contribution to the European post-Fukushima efforts needed to update the Severe Accident Management Guidelines and strategies.

This was achieved through institutional or competitive work like the participation in Euratom FP7 projects in the field and collaboration in the European Networks related to severe accidents, like SARNET-2/PHEBUS-FP and through cooperation with EU TSOs or with the international organizations like the IAEA and the OECD/NEA.

Within its domain of competence, the action contributed to the development and review of the IAEA nuclear safety standards and or to OECD-NEA State Of the Art Reports.

As to advanced reactor designs, this action helped to consolidate the European efforts needed to build a consensus on their required safety level and generated a roadmap for the safety assessment of advanced reactors. Support to the Sustainable Nuclear Energy Technology Platform (SNETP) and the Generation IV International Forum (GIF) was also provided.

3.1. Clients and Stakeholders

The Customer DGs (inside the European Commission) and their level of involvement are listed in the following:

- DG RTD - Recipient of consultancy and services
- DG ENER - Recipient of consultancy and services

The customers/users (outside the European Commission) and their level of involvement are listed in the following:

- Members of the Network SARNET and of NUGENIA TA2: Organisations from Research Institutes and TSOs, Vendors, Regulators and Utilities of all the EU Countries with nuclear installations
- Members of the different Euratom FP7 consortia for the following projects (CESAM, CP-ESFR, LEADER, JASMIN, SARGEN IV): Organisations from Research Institutes and TSOs, Vendors, Regulators and Utilities of all the EU Countries with nuclear installations
- IAEA - Coordination of research priorities, recipient of research, consultancy and services
- OECD/NEA - Coordination of research priorities, recipient of research, consultancy and services

3.2. Major Objectives, deliverables and impacts

OBJECTIVES and MEANS

(1) Research into severe accident modelling, radiological source term evaluation and accident management of NPPs, in coordination with EU Member States activities

(2) Support to DG ENER in the field of Severe Accident and Emergency Plan & Response

(3) Development of international safety research cooperation with key partner countries and relevant international organisations (IAEA, OECD/NEA)

(4) Development and application of tools and methodologies for safety assessments of innovative reactor designs and fulfilling the JRC function of Euratom Implementing Agent for the Generation IV International Forum (GIF) and coordination of the EU contribution to GIF, as requested by Council Decision 05/14929

DELIVERABLES

In terms of deliverables, in the following pages an overview of the main ones for 2012-2013 is provided. More details are provided in section 5.3. The target here is to illustrate the development of the NURAM Action through the deliverables produced.

A) Deliverables to objective 1: *Research into severe accident modelling, radiological source term evaluation and accident management of NPPs, in coordination with EU Member States activities*

As explained in the chapter 2, the NURAM Action has been created in 2012 with a key focus on Severe Accident Modelling for EU NPPs and therefore the deliverables in this topic increased progressively from 2012 to 2013 and have continued to expand in 2014.

The work started by acquiring the latest versions of the severe accident computer codes, training the staff, using these computer codes to model severe accident experiments and finally performing severe accident analyses for one type of NPP as showed below with the deliverables. Work within the CESAM project focused in 2013 on a review of current Severe Accident Management approaches in Europe.

- JRC76843: " Selection, acquisition and installation of reactor physics, thermal-hydraulics and severe accident code system in support of accident analyses of nuclear reactors: ASTEC, RELAP/SCDAP and MAAP4 code Computer codes for NURAM Action", G. Pascal
- JRC81369: " Validation of ASTEC V2.0-rev2 by FARO experiments", S. Hermsmeyer
- JRC84675: " Validation of ASTEC V2.0-rev2 by STORM experiments", M. Sangiorgi
- JRC86713: "Benchmark between ASTEC V2.0 rev3 and MAAP4.0.8 for three Severe Accident scenarios on a PWR1000 MWe" M. Sangiorgi et al
- JRC89305: " CESAM D40.41 - Review of current Severe Accident Management approaches in Europe and identification of related modelling requirements", S.

Hermsmeyer – Published in January 2014

However, with the work which was already ongoing through PHEBUS and SARNET, NURAM contributed already in 2012-2013 to other key activities and in particular Peer Reviewed Papers in the field of Severe Accidents, as showed below:

- JRC69382: "The European Research on Severe Accidents in Generation-II and -III Nuclear Power Plants", SCIENCE AND TECHNOLOGY OF NUCLEAR INSTALLATIONS, Dorsselaere J-P; Auvinen A; Beraha D; Chatelard P; Journeau C; Kljenak I; Miassoedov A; Paci S; Zeyen R
- JRC69657: "Understanding of the operation behavior of a Passive Autocatalytic Recombiner (PAR) for hydrogen mitigation in realistic containment conditions during a severe Light Water nuclear Reactor (LWR) accident", NUCLEAR ENGINEERING AND DESIGN, Payot F; Reinecke E-A; Morfin F; Sabroux J-C; Meynet N; Bentaib A; March P; Zeyen R
- JRC76848: "Containment Behaviour in PHEBUS FP", ANNALS OF NUCLEAR ENERGY, LAURIE Mathias; MARCH P.; SIMONDI-TEISSEIRE B.; PAYOT F.;
- JRC73532: "The objectives of the Phébus FP experimental programme and the main lessons learned", Annals of Nuclear Energy, Zeyen R, B. Clement
- JRC75884: " Phebus FPT3: Overview of main results concerning the behaviour of fission products and structural materials in the containment", NUCLEAR ENGINEERING AND DESIGN, HASTE T; PAYOT F.; MANENC C.; CLEMENT B.; MARCH Ph.; SIMONDI-TEISSEIRE B.; ZEYEN Roland;

B) Deliverables to objective 2: *Support to DG ENER in the field of Severe Accident and Emergency Plan & Response*

In 2012 and partly 2013, the NURAM Action provided a very strong support to DG ENER in the frame of the EU Stress Tests. A NURAM representative participated as reviewer to the whole process of the EU Stress tests (desktop review, topical review and country review) in the WG dealing with Accident Management. He participated as well to the Stress Tests follow up in 2013.

This NURAM representative participated also very actively to the EC Task Force created to supervise and review the work to be done in the frame of DG ENER project concerning “Review of Current Off-Site Nuclear Emergency Preparedness and Response Arrangements in EU Member States and Neighbouring Countries”.

NURAM staff also participated during the year to several IAEA and OECD/NEA meetings and key information regarding nuclear safety collected during these meetings were transferred to DG ENER in the frame of a report at the end of each year (see point C).

Details regarding this support to DG ENER can be found in the two deliverables below.

- JRC76846:"Technical support to DG ENER on Accident Management in the frame of the EC Fukushima Task Force" G. Pascal
- JRC86714: Technical report related to the NURAM participation in the EC Task Force created to supervise and review the work to be done in the frame of DG ENER project concerning “Review of Current Off-Site Nuclear Emergency Preparedness and Response Arrangements in EU Member States and

Neighbouring Countries". G. Pascal

C) Deliverables to objective 3: *Development of international safety research cooperation with key partner countries and relevant international organisations (IAEA, OECD/NEA)*

NURAM staff participated during the year 2012 and 2013 to several IAEA and OECD/NEA meetings and key information regarding nuclear safety collected during these meetings were transferred to DG ENER in the frame of a report at the end of each year (see below).

- JRC76917: "NURAM contribution to IAEA, OECD/NEA, GIF and NUGENIA – workshops and meetings in 2012" M. Strucic
- JRC87307; "NURAM contribution to IAEA, OECD/NEA, GIF and NUGENIA workshops and meetings in 2013" M. Strucic

Furthermore, several key collaborations with the IAEA and OECD-NEA should be mentioned specifically, i.e.:

With the IAEA:

- Support to the development of the "IAEA Comprehensive Report on Fukushima" for the WG3 on EP&R. The report will be published in 2015. G.Pascal
- JRC77638: "IAEA CRP on Heat Transfer Behaviour and Thermo-hydraulics Code Testing for Super-Critical Water Cooled Reactors" L. Ammirabile

With the OECD/NEA CNRA or CSNI: Intensive work was performed in 2013 to support the development of the following reports, most of which have been published in 2014.

- The CNRA Task Group on Accident Management" report:"ACCIDENT MANAGEMENT INSIGHTS AFTER THE FUKUSHIMA DAIICHI NPP ACCIDENT". G. Pascal
- The CSNI report "Status Report on Hydrogen Management and Related Computer Codes", M. Sangiorgi
- The CSNI report "Status Report on Filtered Containment Venting", L. Ammirabile
- The CSNI report "Spent Fuel Pool and assembly accident phenomenology and mitigation strategies", M. Strucic
- The CSNI Task Group on "International benchmarking project on fast-running software tools used to model fission product releases during accidents at nuclear power plants" M. Vela Garcia

D) Deliverables to objective 4: *Development and application of tools and methodologies for safety assessments of innovative reactor designs and fulfilling the Euratom Implementing Agent function for the Generation IV International Forum (GIF) and coordination of the EU contribution to GIF, as requested by Council Decision 05/14929*

The extended work performed for innovative reactors and contribution to GIF was mainly done in the framework of several Euratom FP7 projects and through GIF

Working Groups (examples of the main contributions are given below)

CP-ESFR: Collaborative Project for a European Sodium Fast Reactor

- JRC75275: "CP-ESFR Computation of velocity and temperature profiles in an ESFR fuel assembly in case of Total Instantaneous Blockage (TIB)" A. Grah
- JRC77185: "CP-ESFR - Task 3.4, SP2.1, WP5: Optimization of Cores Study of Control Rod Issues for ESFR Oxide Core. CP ESFR Collaborative Project for a European Sodium Fast Reactor." Haile Tsige-Tamirat
- JRC75415: "CP-ESFR Computation of velocity and temperature profiles in a ESFR fuel assembly" A. Grah

SARGEN IV: Harmonized European methodology for Safety Assessment of innovative fast reactors

- JRC72919: "SARGEN_IV: Proceedings of the Workshop for Dissemination of INPRO and GIF-RSWG Methodologies", L. Ammirabile
- JRC80522: "SARGEN_IV: Proposal for harmonized European practices for the safety assessment of innovative fast neutrons spectrum reactors considered in Europe", L. Ammirabile
- JRC81444: "SARGEN_IV Deliverable D2.5: Identification and Ranking of Safety Issues", K. Tucek

JASMIN: Joint Advanced Severe accidents Modelling and Integration for Na-cooled Fast Neutron Reactors

- JRC83702; "Contribution to JASMIN FP7 competitive project: JASMIN-MODELLING-D2.4 - Detailed specification of neutronics models", Haile Tsige-Tamirat
- JRC83583: "Contribution to JASMIN FP7 competitive project Deliverable D2.2: Review of pin thermal-mechanical models implemented in the SIMMER-III accident analysis code." A. Flores Y Flores

LEADER: Lead-cooled European Advanced Demonstration Reactor

- JRC87309: "LEADER Deliverable DEL026-2013: Safety Authority Advisory Group: comments and recommendations". K. Tucek
- JRC87312: "LEADER Deliverable DEL028-2013: ELFR cores. Summary, synoptic tables, conclusions and recommendations" K. Tucek

GIF Working Groups

- Contribution to the GIF Risk & Safety Working Group document ‘An integrated safety assessment methodology (ISAM) for Generation IV nuclear systems’ http://www.gen-4.org/PDFs/GIF_RSGW_2010_2_ISAMRev1_FinalforEG17June2011.pdf

E) Scientific output

- 7 Scientific Papers were presented at International Conferences (NENE2013, European Nuclear Conference 2013, ICAPP 2013, NURETH-15).
- 16 Peer-reviewed papers were published in ISI listed Journals in 2012-2013

3.3. Major Highlight(s)

With reference to the year 2012 and 2013, the following highlights can be selected from the large R&D output described above:

- Very strong support to DG ENER in the frame of the EU Stress Tests. A NURAM representative participated as reviewer to the whole process of the EU Stress tests (desktop review, topical review and country review) in the WG dealing with Accident Management
- Key role in the Euratom FP7 CESAM project, where NURAM is actively contributing to the whole project and leading the biggest WP (345 MM out of the project total 673 MM), WP40 covering "Plant Application and Severe Accident Management (SAM)"
- Extended contribution to OECD-NEA reports under development after Fukushima on Filtered Venting Systems, Spent Fuel Pool, H2 and Accident Management
- Key role in the Euratom FP7 SARGEN IV project, where NURAM actively contributed to the whole project and led the WP3 covering "Review of safety methodologies for innovative reactors"

4. Further Information

4.1. Integration and Networking

As far as necessary collaborations with other JRC units or JRC institutes are set-up, mainly through participation to the same competitive projects of DG_RTD: SARNET II, CP-ESFR, JASMIN, etc...

Collaboration with a large number of international partners (from EU MS in particular) is performed on a continuous basis through participation to Euratom FP7 projects but also to IAEA activities or OECD/NEA reports development.

At the end of 2013, following a request from one EU partner (UJV Rez), the JRC also launched an International Benchmark of In Vessel Retention (IVR) modelling for VVER1000. More than 10 EU and non EU partners immediately expressed interest in participating and the Kick off Meeting took place in Petten in November 2013. The project will be running until beginning of 2015.

4.2 List of Competitive Activities

The competitive activities are performed through Euratom FP7 projects. These projects have been mentioned above; a few further lines of description are given below:

SARNET II: (Severe Accident on LWRs network of Excellence)

Most of the actors involved in severe accident research in Europe, plus Canada, Korea and the United States (41 partners), networked in SARNET2 (Severe Accident Research NETwork of Excellence - Phase 2) their capacities of research in order to resolve important pending issues on postulated severe accidents of existing and future Nuclear Power Plants (NPPs). The project was defined in order to optimise the use of the available means and to constitute a sustainable consortium in which

common research programmes and a common computer tool to predict the NPP behaviour during a postulated severe accident (ASTEC integral code) could be developed.

CESAM: (Code for European Severe Accident Management (LWRs))

The CESAM (Code for European Severe Accident Management) R&D project, coordinated by GRS, started in April 2013 for 4 years in the 7th EC Framework Programme of research and development of the European Commission. It gathers 19 partners from 12 countries.

ASTEC, jointly developed by IRSN and GRS, is considered as the European reference code for severe accident since it capitalizes knowledge from the European R&D in the domain. The project aims at its enhancement and extension for use in severe accident management (SAM) analysis for all types of Nuclear Power Plants (NPP) of Generation II-III presently under operation or foreseen in the near future in Europe, spent fuel pools included.

CP-ESFR: (Collaborative Project for a European Sodium Fast Reactor)

The new reactor concepts proposed in the Generation IV International Forum (GIF) are conceived to improve the use of natural resources, reduce the amount of high-level radioactive waste and excel in their reliability and safe operation. Among these novel designs, sodium fast reactors (SFRs) stand out due to their technological feasibility as demonstrated in several countries during the last decades. As part of the contribution of EURATOM to GIF the CP-ESFR was a collaborative project with the objective, among others, to perform extensive analysis on safety issues involving renewed SFR demonstrator designs.

LEADER: (Lead-cooled European Advanced Demonstration Reactor)

The LEADER project dealt with the development to a conceptual level of a Lead Fast Reactor Industrial size plant and of a scaled demonstrator of the LFR technology. The project was based on previous achievements obtained during the 6th FP of the EU in the ELSY project but took into account the indications emerging from the European Strategic Research Agenda as well as the main goals of the European Industrial Initiative on Fission. As a consequence the project was strongly committed to the conceptual design of a scaled/demonstrator reactor to be constructed in the relatively short term.

The project provided for an important involvement of End-Users and Safety Authorities from the beginning of the design process to help the plant conception and to assure high safety standards. Education and Training activities were included in a specific work package where European Universities were directly involved with the aim to develop the future nuclear energy designers.

JASMIN: (Joint Advanced Severe accidents Modelling and Integration for Na-cooled Fast Neutron Reactors)

The project supports the ESNII (European Sustainable Nuclear Industrial Initiative) roadmap and the Strategic Research Agenda and the Deployment Strategy of SNETP (Sustainable Nuclear Energy Technology Platform) on the enhancement of Sodium-cooled Fast neutron Reactor (SFR) safety, especially towards a higher resistance to severe accidents.

In the initiation phase of SFR core disruptive accidents, it is essential to investigate

the impact of new core designs that may disperse core debris and minimize risks of core compaction. The available codes today have been developed in the 80's. The objective is to develop a new European simulation code, ASTEC-Na, with improved physical models, accounting for results of recent LWR research, with modern software architecture and high flexibility to account for innovative reactor designs. It will be based on the ASTEC European code system, developed by IRSN and GRS for severe accidents in water-cooled reactors. This will allow capitalizing the state-of-the-art knowledge on SFR severe accidents.

SARGEN IV: (Harmonized European methodology for Safety Assessment of innovative fast reactors)

The European Sustainable Nuclear Industrial Initiative was launched in November 2010 to anticipate the development of a fleet of fast reactors with closed cycle. Three fast neutron technologies have been selected:

- the Sodium cooled Fast Reactor with the ASTRID prototype
- the Lead cooled Fast Reactor with the ALFRED demonstrator
- the Gas cooled Fast Reactor with the ALLEGRO demonstrator,

with the support of:

- a Fast Spectrum Irradiation Facility (ADS-LBE, i.e. MYRRHA/FASTEF)

With the objective of future assessment of these advanced reactor concepts, the SARGEN_IV Project is intended to gather safety experts from recognized European Technical Safety Organizations, from Designers and Vendors, as well as from Research Institutes and Universities to:

- develop and provide a tentative commonly agreed methodology for the safety assessment,
- identify open issues in the safety area, mainly addressing and focusing on assessment relevant ones,
- detect and underline new fields for R&D in the safety area
- provide a roadmap and preliminary deployment plan for safety-related R&D, including cost estimation.

4.3. Mobility and training of researchers

Due to the research topics of the Action, NURAM is continuously hosting short term collaborators with great experience of nuclear power plant operation and severe accident. This collaboration is fruitful for both sides: NURAM outputs and for the short term researcher who takes advantage of the NURAM environment and networks.

5. Other Information

5.3. Publications, Technical Reports, Thesis

	Total
Article contribution to a peer-reviewed periodical listed in the ISI SCI-exp and/or SSCI	10
JRC Scientific and Technical Reports	30
Books	1

EUROPEAN COMMISSION
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Ex post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action *52201 SNF*
Safety of Nuclear Fuels and Fuel cycles
Action Leader: *Paul Van Uffelen, E03*

Authorising Officer: *Joe Somers, E04*
Leading Institute: *Institute for Transuranium Elements*

0. Policy Area

FP7 Policy Theme	5 The EURATOM programme
Agenda No & Title	5.2 Nuclear safety
Sub-Agenda No & Title	5.2.2 Nuclear fuel safety in power reactors operating in the EU

Link with Policy area(s): Energy

1. Rationale of the Action

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 cautious and push for higher safety standards, 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 (MOX fuel). The deeper understanding of the in-pile behaviour of nuclear fuel under off-normal and accident conditions enables improvement of the response and precautions to be taken if such events occur. The experimental post-irradiation investigations also deliver input to the fuel performance codes, and the JRC-ITU TRANSURANUS code is continuously updated and improved to the benefit of safety authorities in the European Union and candidate countries. In the frame of the Generation IV (GEN IV) International Forum (GIF) the safety of advanced sustainable fuels and their fuel cycles needs to be established, in collaboration with member state organisation in support of the ASTRID, ALLEGRO, ALFRED and MYRRHA prototypes, under the auspices of the European Sustainable Nuclear Industrial initiative (ESNII).
With the acquired knowledge, JRC can maintain and develop its position as an independent advisor to the Commission and Member States on nuclear fuel related issues. In doing so, JRC made an important contribution in the quest for safe, sustainable, proliferation resistant nuclear energy to fulfil the needs of future generations.

2. History and development of the Action

The Safety of Nuclear Fuels action was the result of the merging of two actions in 2013: Safety of Conventional Fuels (SCNF, 52201) and Safety of Advanced Nuclear Fuels (SANF, 52301). The SANF action was launched in January 2007 and was new in FP7. Its inception was a response to the changing and promising renaissance in nuclear energy, and contributed to focus resources of the JRC to GIF. Efforts were being directed to complement the excellent experimental work at JRC-ITU with more theoretical support and to improve the scientific basis underpinning nuclear fuel behaviour. This resulted in our participation in the system steering committee for the sodium cooled fast reactor, as well as the project management boards of the corresponding advanced fuel project along with the fuel and core materials project for the gas-cooled fast reactor project of GIF.
The SCNF action belonged to the core competences of JRC-ITU from the beginning. Within the FP7, the emphasis in the action gradually shifted from the traditional post-irradiation techniques providing information on microstructure and fission gas release to advanced techniques providing fundamental data on the thermo-physical and thermal-mechanical properties of nuclear fuel. Such techniques include the laser flash

device that has provided much new data on the thermal conductivity of high burn-up UO_2 fuel and MOX fuel. Secondary ion mass spectrometry is another advanced technique that has recently been introduced into the action and has already found an important application in the determination of B and Li in the external oxide corrosion layer of the Zircaloy cladding of spent fuel. These techniques have put the action in the forefront of studies of the in-pile behaviour of nuclear fuel and have resulted in JRC-ITU becoming a leading member in the international NFIR Programme, which is studying the fragmentation of nuclear fuel during temperature transients and the high burn-up properties of a number of LWR fuel variants. The action was therefore also very well placed to meet the needs of its customers and partners.

3. Description of the Action

The SNF action contributed to the three pillars of the Sustainable Nuclear Energy Platform (SNE-TP) of the EU.
The contribution to the first pillar of SNE-TP addressing reactors of Generation II and III (now covered by the activities of NUGENIA), is focused on the elucidation of the properties and performance of conventional nuclear fuel (UO_2 and MOX) at extended burn-up and on studies of the behaviour of nuclear fuel under accident conditions. The work is highly coupled to the frame of Framework Programme (FP) 7 projects such as F-BRIDGE and international projects such as NFIR, or SARNET as well as ISTC projects. It included atomic-scale simulations that shed more light on the underlying basic mechanisms affecting the material properties during irradiation. Attention also turned to doped fuels in the frame of the EPRI NFIR-V programme (in addition to bilateral contracts with AREVA); to which numerous industries and research organisations from the EU member states participate.
Novel experimental facilities were constructed and existing ones were further developed in order to deliver an extended set of reference data of mechanical and thermal properties of nuclear fuel and fuel components. More precisely, the efforts focused on the elastic modulus of irradiated oxide fuels by means of the micro-acoustic method, the determination of the UO_2-PuO_2 phase diagram, and on the more accurate assessment of the thermal diffusivity of nuclear materials by means of the POLARIS setup.
The experimental investigations fed into simulation tools such as atomistic models and the integral fuel-rod performance code TRANSURANUS, widely used in EU member states by technical safety organisations (TSOs) for nuclear regulatory support, and research and industrial organisations for modelling fuel under conditions ranging from normal to design basis accident conditions. JRC-ITU has improved the various models that deal with transient conditions and design basis accident conditions such as a loss of coolant accident. The basic principles of fuel behaviour modelling have also been disseminated via international summer schools, e.g. the Frederic Joliot-Otto Hahn School or summers schools organised by the OECD-NEA
To understand the radioactive releases in case of incidents, accidents and the events leading to melting of the reactor core (as for example in the case of the Fukushima type accidents), the investigation of fission gas release from irradiated fuel samples was studied by mass spectrometry, and physical and chemical interactions that occur between the reactor components and fuel rod constituents have been analysed. The goal was to cover specific compounds and conditions needed for assessing the source term. The work involved collaboration with EU and Japanese nuclear safety organisations as well as the IAEA and neighbour countries (supported by JRC's enlargement and integration funds).

The contribution of this action to the second pillar of SNE-TP addressing next generation reactors, forms part of the EURATOM contribution to the Generation IV (Gen IV) International Forum (GIF). Fuel safety aspects of the Gen IV Gas, Sodium, and Lead fast reactor (GFR, SFR, LFR) systems were covered in a comprehensive set of investigations covering safe synthesis of oxide, nitride, and carbide fuels containing minor actinides, in both homogeneous and heterogeneous recycling strategies, the study of basic fuel properties, fuel coolant and cladding interactions, and irradiation behaviour. The goal of this work is establishing safety limits for fabrication, and in pile performance of the advanced fuels required for these reactor systems. Support to member state organisations has been achieved via participation in the Indirect Action projects such as ESFR.
Within the context of the FP7 project F-BRIDGE and the collaborations with EC member state organisations, research has been undertaken to improve our basic understanding of these complex fuel materials. Unique results have been obtained on the crystal and defect chemistry of fuel materials by means of the new nuclearised NMR at JRC-ITU in combination with EXAFS and XRD, on the radiation effects in nuclear fuels by the new state-of-the-art nuclearized transmission Electron Microscope (TEM), on the role of fission products on the fuel properties by means of density function theory (DFT) calculations. This information has been successfully integrated in and used for the development of models to predict the performance of these fuels by means of the JRC-ITU TRANSURANUS code.
As contribution to the Very High Temperature Reactor (VHTR) research for another Generation IV concept, the fuel performance and safety limits in the Very High Temperature Reactor (VHTR) were analysed via post-irradiated testing of advanced coated particles in the KÜFA device of JRC-ITU. It is also essential to preserve and disseminate this knowledge, which was accomplished by means of contributions from JRC-ITU to the ARCHER Eurocourse. Finally, the experiments were complemented by dedicated basic science studies on the properties of SiC in such fuels and with DFT based molecular dynamics and accelerated dynamics simulations. These helped improving the understanding of silver and caesium migration along grain boundaries in SiC, which constitutes the first safety barrier for release to the environment. The action contributed extensively to the ARCHER project.

3.1. Clients and Stakeholders

Industry:	AREVA, NEXIA Solutions, S.A. Belgonucleaire, General Atomics, AMEC NNC, PBMR, Armenian NPP, NASA, Kozloduy NPP, NRA Bulgaria, Westinghouse Electric Sweden, FORTUM, CEZ, E.ON, EPRI, EdF, NPP Obrigheim, NPP Slovak , CRIEPI, CERCA France
Universities:	Delft University of Technology, University of Pisa, Imperial College London, University of Manchester, Cambridge University, Politecnico di Milano, Queen Mary University of London, Ecole Centrale of Nantes, Rheinisch-Westfälische Technische Hochschule Aachen, Universidade de Santiago de Compostela , Ecole Polytechnique de l'Université d'Orléans, Technical university of München, Technical university of Sofia, Royal institute of Technology Sweden, Czech Technical university Prague, Institut national polytechnique de Lorraine,

	LAIN university of Montpellier II, University of Bremen, Atomenergoprojekt Russia
National research organisations:	AEC, CEA, JAERI, KAERI, KIT, FZJ, NRG, PSI, US DOE, SNL, ORNL, SCK-CEN, UJV, INRNE, HZDR, INL, VTT, MTA EK (AEKI), NPL, ENEA, CIEMAT, Institute for atomic energy Poland, INR,Bochvar State Institute, Kurchatov institute, Moscow Power Engineering Institute, VUJE
National safety authorities:	GRS, IRSN, TÜV, Armenian NRA, ENSI Switzerland, State Office for Nuclear Safety Czech Republic
International organisations:	IAEA, OECD-NEA, GIF
From the European Commission:	DG RTDI, DG ENER

3.2. Major Objectives, deliverables and impacts

Objective 1: To provide the European Nuclear Stakeholders (fuel vendors, operators of nuclear reactors, utilities and national licensing authorities) with reference experimental data about fuel from current reactors to ensure that safety criteria are met and not exceeded (e.g. High Burn-up Fuel Properties).

Deliverables

(a) State-of-the-art new equipment: shielded electron microprobe analyser, quantitative gas analytical measurement system for fission gas and helium from irradiated fuel samples, and micro-acoustic setup for mechanical properties of fuel,

(b) Unique data on the thermal diffusivity and fission gas release of irradiated nuclear fuel at high burn-up (80-100 MWD/kgHM) in UO_2 and MOX, with information about the influence of the high burn-up structure (HBS) on the thermal conductivity and fission product behaviour of nuclear fuel

(c) Information on the pressurised state of the pores of the high burn-up structure, and on the effect of the HBS on the fragmentation of nuclear fuel during a rapid temperature rise.

(d) Publications in peer reviewed journals and reports as well as other transfer or knowledge via training and education activities

Impacts

The improvement and renewal of equipment ensures that JRC-ITU continues to play a world-leading role as a laboratory for material studies and post-irradiation examination of commercial nuclear fuel in order to provide our customers and stakeholders unique and high quality data of safety-relevant thermo-physical and mechanical properties related to the high burn-up structure and its effects, which will enable them to make safety cases for the extension of the operating time of the fuel and to accurately predict the behaviour of nuclear fuel under off-normal and accident conditions.

Objective 2: To provide the European Nuclear Stakeholders (fuel vendors, operators of nuclear reactors, utilities and National Nuclear Regulatory Authorities) with a state-of-the-art computer code that accurately predicts all important safety aspects of nuclear fuel performance under normal and off-normal irradiation conditions, along with an interface for coupling this tool with other simulations tools applied for the nuclear reactor safety analysis.

Deliverables

(e) State-of-the-art nuclear fuel performance code TRANSURANUS (with manual) that includes updated or new material properties for new fuels and cladding materials as well as more sophisticated models for large clad deformations and models for the formation of the high burn-up structure. The final report for the IAEA benchmark (FUMEX-III), for which JRC-ITU provided consulting to the IAEA, evidences the current state of modelling.

(f) Interface for the coupling of the TRANSURANUS code with reactor physics and thermal-hydraulic code (e.g. with DYN3D code of HZDR)

(g) Training courses for users, covering both the theoretical background and practical exercises

(h) User group meetings in the form of international workshops

(i) Peer reviewed papers and conference contributions, PhD thesis

Impacts

The deliverables allow improving the general understanding about fuel behaviour as well as the subsequent refinement of a reference simulation tool used by technical safety organisations, universities, research centres and fuel designers. These stakeholders and customers in the EU have therefore access to a flexible, comprehensive computer code that accurately predict all important aspects of conventional and GEN IV fuel performance under normal, off-normal and transient irradiation conditions.

The action also contributed to the assessment of the code coupling, which prepares the grounds for the development of a platform for multi-physics reactor safety simulations by coupling the TRANSURANUS code to other neutron-physics and thermo-hydraulics codes, which has been launched by various EU member organisations.

Objective 3: To understand the sequence of events involved in a severe nuclear accident leading to melting of the reactor core, with a particular focus on the physical and chemical interactions that occur between the reactor components and fuel rod constituents, the properties and behaviour of the compounds formed by such interactions and the consequences for the source term release (as for example in the case of the Fukushima type accidents).

Deliverables

(j) New equipment: POLARIS setup with high power laser for thermal and transient behaviour assessment, setup for re-vaporisation studies of radioactive fission products

(k) The International Nuclear Materials Conference (NUMAT) was devised by JRC-ITU and held for the first time in 2010 in collaboration with Elsevier and IAEA. The conference QUENCH was co-organised by JRC-ITU and the IAEA

(l) Peer reviewed articles, conference papers and reports, e.g. about assessing the effect of non-stoichiometry and composition changes occurring under off-normal conditions on the thermal properties of oxide fuels, and about revaporisation of fission products in the course of a severe accident.

Impacts

Dissemination of reference knowledge to technical safety organisation and nuclear regulatory authorities worldwide (present at the NUMAT Conference, the QUENCH workshop and the FUMEX-III project meetings) about phenomena during loss of coolant accidents (LOCA) and the early phase of severe nuclear accidents, including materials interactions, oxidation and hydrogen source term at high temperatures as well as coolability and reflood of an overheated reactor core. The outcome provided a forum for collaboration between scientists of safety authorities and research centres from Russia, the Member States of the European Union and Japan. The outcome of the final FUMEX-III meeting also defined the needs for code benchmarking in the coming years.

Objective 4: Assess material properties relevant for the safety of advanced nuclear fuels, cladding materials, and coolants.

Deliverables

(m) New equipment: coated particle synthesis and characterisation of SiC, post irradiation examination of fission product release from coated particles (KÜFA) in loss of coolant situation, corrosion testing equipment for coated particle fuel, solid state nuclear magnetic resonance (NMR) for detailed studies of point defects in nuclear materials, electro-magnetic pulse technology (EMPT) equipment for assessment of tightness of new cladding types

(n) Samples of actinide oxide, nitride and carbide compounds and basic safety testing studies at high temperatures, such as melting temperature, thermal conductivity and vapour pressure determination, and phase diagram studies

(o) Post irradiation examination data (e.g. scanning electron micrographs) of nitride and carbide fuel from the NIMPHE II project

(p) Nano-crystalline UO_2 samples for deeper assessment of HBS properties (e.g. thermal conductivity)

(q) Data about interaction of fuel, air coolant and cladding

(r) Peer reviewed articles and reports, PhD thesis

(s) Contributions to the strategic research agenda of the "Sustainable Nuclear Energy. Technology Platform" (SNE-TP) and in the elucidation of the NUGENIA roadmap

(t) Contribution to the European Sodium Fast Reactor Roadmap

(u) EURATOM contribution to GIF project management Boards (SFR and GFR)

(v) Establishing Fuel sub-programmes in EERA Joint Project on Nuclear Materials (JPNM)

Impacts

On the basis of the deliverables customers and stakeholders will have unique data for the coated particles that will enable them to design advanced nuclear fuels and carry out safety studies for VHTR fuel under off-normal and accident conditions. A part of the experimental know how has been sold via a third party contract that has been signed with INET in China for post irradiation examination (start in 2015) of the fuel pebbles irradiated in the HFR.

Through the leading role in both Indirect Actions and the GIF fuel project management boards, the SNF action contributes to the necessary synergy, and provides the JRC with the appropriate information for its advising role to the EU policy makers. Furthermore, the Strategic Research Agenda provides decision makers and the scientific community at large with research, development and demonstration road maps to achieve the short (2012), medium (2020) and long term (2040-2050) goals of the SET Plan. Finally, the action is contributing to the establishment of the European Research Area as well as to the establishment of Europe's low carbon energy policy, as specified in the SET Plan.

3.3. Major Highlight(s)

Within the NFIR IV project that involves nuclear industry from the EU (e.g. AREVA), JRC-ITU together with CEA, provided the main experimental post irradiation experimental data from fuel disks with different burn-up and/or initial structure and composition irradiated in the OECD Halden reactor. These data are crucial for understanding the development and behaviour of the HBS under steady-state as well as loss of coolant conditions such as fragmentation and fission gas release.

In view of the new value for the melting temperature of PuO_2 that has been found in our unique laser melting experiments, being more than 300 Kelvin higher than the accepted value, the UO_2-PuO_2 phase diagram has been revisited, with major changes in the PuO_2-rich part. This work was performed in the frame of the F-BRIDGE project,

A series of experiments in the KÜFA installation of ITU, simulating irradiated coated particle UO_2 fuel during a loss of coolant accident in a high temperature reactor, confirmed the excellent inherent safety features of this fuel in terms of radioactive fission product release up to 1600^oC.

Several JRC-ITU staff members from the SNF action contributed to the roadmap for research and development for fuel for the European sodium cooled fast reactor in the frame of the EISOFAR and ESFR projects, as well as to the Strategic Research Agenda of the sustainable nuclear energy technology platform (SNE-TP) which formulated research topics relevant for fuel and simulations tools of the SNE-TP in the short, medium and long term.

First fundamental results have been obtained by means of the new NMR facility at the JRC-ITU in combination with EXAFS and XRD for an analysis of point defects in

uranium carbides, and by means of DFT calculations for the analysis of fission products in uranium nitrides. Experimental investigations examined irradiation damage in nitride fuels and confirmed the melting temperatures of both UN and (U,Pu)N.

Many staff members of JRC-ITU contributed various chapters to a five-volume major reference work "Comprehensive Nuclear Materials", for which the chief editor was the unit head of the Materials Research unit from JRC-ITU.

A new version of the TRANSURANUS software involved in the safety analysis of nuclear fuel has been developed and distributed to users from the safety authorities, industry, research centres and universities in the EU member states. The new models were verified in the frame of the FUMEX-III benchmark for fuel performance codes of the IAEA.

JRC-ITU took the initiative to make a concept for an international conference on nuclear materials, the Nuclear Materials Conference (NUMAT) and successfully organised the first edition in 2010 in Karlsruhe in collaboration with Elsevier and the IAEA. This conference is now organised on a bi-annual basis, and has quickly become the main forum in the nuclear materials field.

Finally, the former unit head of the Materials Research unit at JRC-ITU, Mr. Claudio Ronchi, was attributed the Robert Cahn Award from Elsevier for his lifetime achievements in the field of nuclear materials.

4. Further Information

4.1. Integration and Networking

JRC internal collaborations

The internal collaboration between JRC institutes, namely JRC-IET, JRC-IPSC and JRC-ITU, was strongly integrated in several FP7 indirect actions (see 4.2. below): EISOFAR, ESFR, MTR-I3, SARNET, NUGENIA, ARCHER, GETMAT, EURACT-NMR, PELGRIMM, MARINE, SEARCH, JASMIN, METROFISSION and GENTLE. Both JRC IET and ITU contribute to the management of the EERA JPNM programme.

Networking with external organisations

The indirect actions in FP7 are important seeds for collaboration with external organisations of the EU member states, with a strong component of joint programming to answer to the research direction and priorities defined by DG RTDI. The prominent participation of JRC-ITU, for example in the F-BRIDGE project and in the preparation of the strategic research agenda for SNE-TP, resulted also in our participation in the European Energy Research Alliance (EERA) coordination body for publicly funded R&D. More precisely, together with different research organisations from two member states, JRC-ITU has introduced the nuclear fuel research in the Joint Programme for Nuclear Materials. Furthermore, regular bilateral meetings with major nuclear research organisations in Europe (CEA, SCK-CEN, KIT, NRG) resulted in a joint approach to technological questions and in an efficient usage of research tools in nuclear fuel research. JRC is the implementing agent for EURATOM in GIF, and its staffs are fervently contributing to the success of the SFR AF and other projects.

The TRANSURANUS fuel performance code is an important product from JRC-ITU in the context of networking with external organisations. At present TRANSURANUS

user license agreements have been established with around 25 universities, research centres, safety authorities and industrial partners across the EU, as well as Argentina, Armenia, Indonesia, Ukraine and Switzerland, thus constituting a substantial network in the field of modelling and simulation of nuclear fuel behaviour. Workshops for users are organised on a bi-annual basis, as well as training courses. Furthermore the code is extensively used in the benchmarks for fuel performance role organised by the IAEA and the OECD-NEA, and the JRC-ITU staff members play a leading role in the IAEA Coordinated Research Projects on the improvement of computer codes used for fuel behaviour simulation (FUMEX-II, III and currently FUMAC).

JRC-ITU staffs involved in the SNF action are

- Euratom representative in the fuel management board of GIF
- Euratom representative in the Working Party on Scientific Issues of the Fuel Cycle (WPFC) of the OECD-NEA
- member of the expert group on innovative fuel that reports to the WPFC and focuses on fuels containing minor actinides.
- chair of the working group on fuel for the Kompetenz Verbund Arbeitskreis VHTR that aims at knowledge preservation in Germany.
- Euratom representative in the working party for multi-scale modelling of fuels and structural materials for nuclear systems (WPMM) of the OECD-NEA
- member of the expert group on reactor fuel performance, and of the expert group on validation and benchmarking of methods that report to the WPMM
- member of the technical working group on fuel performance and technology of the IAEA.

Collaboration agreements with Imperial College London and the Institut de Radioprotection et de Surete Nucleaire (IRSN) have been signed in the field of nuclear fuel research. JRC-ITU staffs involved in the SNF action are the steering committee members for both collaboration agreements.

A bilateral project between JRC-ITU and the CEA, called NIMPHE 2, consisted of the fabrication and evaluation of mixed (U,Pu) carbide and nitride fuels. The fuels were fabricated by both JRC-ITU and CEA and irradiated in the Phénix reactor. The non-destructive and some of the destructive testing of NIMPHE 2 (U,Pu)N and (U,Pu)C rods were carried out at ITU.

Finally the action also is involved in projects managed by ISTC Moscow, FUMEX-III of the IAEA, NFIR project managed by EPRI in the USA and the Halden Reactor Project of the OECD-NEA.

4.2 List of Competitive Activities

Coordination of indirect actions
The action was involved in a number of Indirect Actions, including active participation in a coordinating role (leading a work package) in five such actions

- PUMA: Plutonium and Minor Actinide Management by gas cooled Reactors, (STR 30194), 2006-2009, with a budget of 190 k€ for ITU. The project is concerned with the issue of using a Gen IV reactor operating with thermal neutrons for the incineration of minor actinides and plutonium. A staff member of JRC-ITU is leader of a work package (WP) that is based on the fuel for such a reactor type. In addition he was member of the Executive committee, and also held the position of chairman of the Governing board (elected).

- GCFR: Gas Cooled Fast Reactor (STREP 22391), 2005-2009, with a budget of 296 k€ for ITU. A staff member of JRC-ITU was leading WP2, which was concerned with the fuel for this reactor.

- EISOFAR: Roadmap for a European Sodium cooled Fast Reactor by 2020, (SSA 30250), ended in 2007, with a budget of 44,5 k€ for ITU. The EISOFAR programme is a concerted action.

- ESFR: European Sodium Cooled Fast Reactor (CP 31104), 2009 – 2013, with a budget of 786 k€ for ITU. JRC-ITU acts as work package leader on fuel.

- F-BRIDGE: Basic Research for Innovative Fuel Design for GEN IV systems (CP 30954), 2008 – 2012, with a budget of 2 M€ for JRC-ITU. JRC-ITU staff members are leading the domains dealing with basic research and the application to advanced sphere-pac fuel designs, as well as leading a work package about the transfer of basic research and mesoscopic results to macroscopic models and fuel performance codes.

- ARCHER: Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D is an R&D activity (Agreement 269892) in support of the implementation of the Strategic Research Agenda of SNE-TP 2010-2013 and is embedded in the international framework via GIF, as well as in collaboration with IAEA and ISTC. The budget for the JRC is 665 k€.

- METROFISSION: The European Metrology Research Programme (EMRP) is a metrology-focused European programme of coordinated R&D that facilitates closer integration of national research programmes. It is elaborated and executed by the European Association of National Metrology Institutes (EURAMET). It is supported by the European Commission through Article 169 (A169) of the European Treaty. MetroFission is one of the Joint Research Projects selected in the frame of the EMRP Call 2009 “Energy” and co-ordinated by NPL. This project "Metrology for new generation nuclear power plants" started in 2010 and was complete in 2013.

Participation in Indirect Actions
The action was also involved in a number of other Indirect Actions

- RAPHAEL: Reactor for Process Heat, Hydrogen and Electricity generation, (IP 22835), 2005-2009, with a budget of 458 k€ for JRC-ITU. It is an integrated project wherein JRC-ITU performed activities in the realm of safety testing of high temperature reactor fuel.

- GoFastR: European Gas Cooled Fast Reactor (CP-249678) is a small or medium-scale focused collaborative project (2010-2013) co-ordinated by AMEC, with a budget of 255 k€ for JRC-ITU. JRC-ITU played a leading role in the second work package dealing with fuels and core materials and contributed to the fuel safety studies.

- EURACT-NMR: Trans-National Access to Unique European Actinide and Radiological Nuclear Magnetic Resonance Facilities is a coordination and support action (Agreement 269923) that started in 2011 for 30 months, with a budget of 156 k€ for JRC-ITU.

- SNE-TP: Sustainable Nuclear Energy Technology Platform, (CA 30193), 2006-2008, with a budget of 12 k€ for ITU. It is a concerted action supported within which JRC-ITU provided input into the SNE-TP vision document and the launching of the Sustainable Nuclear Energy technology platform (SNE-TP).

- HTR-F1: High Temperature Reactor (SCA 18398), 2001-2007, with a budget of 703 k€ for JRC-ITU. JRC-ITU provided studies on high temperature reactor fuel safety testing.

- GETMAT: Materials for GenIV, (CP 30943), 2008-2013, with a budget of 388 k€ for JRC-ITU. JRC-ITU contributes in this collaborative project through welding technology development for fuel pins.

- JASMIN: Joint Advanced Severe accidents Modelling and Integration for Na-cooled fast neutron reactors (CP 295803) is a collaborative project CP-FP Small or medium-scale focused research project , with a budget of 255 k€ for JRC-ITU. It started in 2011 for 48 months and is co-ordinated by IRSN. The main contribution of JRC-ITU contribution consist of a study the chemical interaction of GEN-IV MOX fuels with sodium, comprising phase diagram investigations.

- SEARCH: Safe ExploitAtion Related CHemistry for HLM reactors is a collaborative project (CP 295736) as support for ESNII roadmap for MYRRHA for the licensing process that started in 2011 for 36 months, with a budget of 224 k€ for ITU.

- PELGRIMM: PELlets versus GRanulates: Irradiation, Manufacturing & Modelling is a collaborative project (agreement 295664) with R&D activities in support of the implementation of the Strategic Research Agenda that started in 2013 for 48 months. JRC-ITU contributes to the fuel synthesis as well as the development and validation of the simulation tools with a budget of 616 k€.

Projects funded exclusively by industrial partners

Agreements were signed with AREVA-NP, Westinghouse Sweden Electric, BNFL, E.ON Kernkraft, CEZ – Temelin, AECL, SCK-CEN and CRIEPI.

An agreement has been signed with INET in China. JRC-ITU will examine their coated particles after irradiation in the HFR reactor in Petten.

4.3. Mobility and training of researchers

The action is involved in the training of students (Master Degree) and young researchers (PhD students and post-doctoral students). During the reporting period 7 Master thesis students carried out a traineeship, while 7 PhD students, 11 post-doctoral fellows, have been part of the staff. In addition two seconded national experts were hosted.
In addition, close collaboration is existing with several universities in the EU, leading to joint work on nuclear fuel behaviour, and as a result JRC-ITU staff is closely involved in the supervision and guidance of MSc (5) and PhD (3) students who spent short term visits (from 2 weeks up to 6 months) at JRC-ITU as unpaid visiting scientist.
At the end of FP7 JRC has had a major role in the definition and preparation of the GENTLE project on life-long learning in the nuclear field, and this project has been received funding from DG RTDI and started in 2013. JRC (IRMM, IET and ITU) have a leading role in the coordination of this project.

5. Other Information

5.1. Publications, Technical Reports, Thesis

Category	Total period
Article contribution to a peer-reviewed periodical listed in the ISI SCI-exp and/or SSCI	79
JRC Scientific and Technical Reports	86
PhD Thesis	8
Books and monograph	14

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2011

Action 52302 *FANGS* Feasibility Assessment of Next Generation nuclear energy Systems

Action Leader: *Michael FÜTTERER*

Authorising Officer: *Peter HÄHNER F04*

Leading Institute: *Institute for Energy and Transport*

0. Policy Area

Policy Theme: 5. EURATOM programme
Agenda N° & Title: 5.2 Nuclear Safety
Sub-agenda N° & Title: 5.2.3 Safe Operation of Advanced Nuclear Energy Systems

1. Rationale of the Action:

Today in Europe, nuclear energy produces about 1/3 of all electricity and about 2/3 of low carbon electricity. The vast majority of energy system scenarios for 2050 predict at least a 20% share of nuclear electricity production in Europe. To make nuclear technology fit for new requirements, nuclear power plants of the next generation shall feature enhanced safety and reliability, minimized waste, resistance to proliferation, sustainability, and competitiveness. Worldwide, thirteen 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.
The rationale for the FANGS action was the need to assess the evolving technical capabilities of various next generation nuclear power systems against the energy policy goals of EU countries, specifically excellent safety and low-carbon efficiency as required by the SET Plan, increasingly also in view of European industrial competitiveness and security of energy supply. Examples for such nuclear systems are the 6 reactor concepts selected by GIF. The goal of the action was to produce the information required by Euratom (e.g. on safety performance, technology readiness, fuel cycle and waste production) for implementing its responsibilities if one or several of these concepts are considered suited for industrial deployment in a European member state. This implied well-coordinated scientific and technical work through both direct JRC projects and through related European competitive projects. Much of the obtained results were exchanged with related GIF projects.
Both, the direct JRC contributions to these projects and the indirect actions (RTD-funded) covered by FANGS were programmed in close cooperation with the relevant networks and in particular with SNETP. Research needs were identified and prioritized, demonstration projects were supported, and scientific results were produced and shared.
FANGS addressed identified key feasibility issues of most of the GIF concepts and their potential applications for electricity generation, cogeneration of heat and power and thermochemical bulk H_2 production. This encompassed fuel and material testing, and safety/feasibility analyses. Starting with the 2009 Work Program, material testing was further strengthened and singled out into the new MATTINO action. The activities relied on well-established and recognized existing infrastructures (HFR, irradiation rigs, test facilities) as well as on experimental and analytical expertise at JRC-IET.

2. History and development of the Action:

In 2007 and 2008, the action was called "Safety of Innovative Reactor Designs" (SAFETY-INNO) and comprised 4 objectives including one dedicated to advanced reactor material research:

1. Fuel and Component Tests
2. Qualification of materials for innovative reactors through material

tests
3. Evaluation of feasibility, safety and performance of next generation nuclear reactors and fuel cycles
4. Contributions to improving European and International Cooperation

In 2009, the materials objective (2) was singled out and enlarged in a new separate action (52304 MATTINO). Until the end of 2010, the other part of the action focused on selected key feasibility aspects of new nuclear energy systems, which is why the action was renamed to "Feasibility Assessment of Next Generation nuclear energy Systems" (FANGS). In 2011, next to the scientifically productive safety and feasibility research, the policy support aspect of FANGS was strengthened by further enhancing work with SNETP and with GIF projects.
As a result, FANGS provided strategy input to European and international cooperation with supporting experimental and analytical efforts to appropriately understand and evaluate nuclear energy systems, their applications and possible implementation to achieve SET Plan targets.
Following the Fukushima accident in March 2011, the action FANGS was discontinued in the course of 2011 in favour of a new action (NURAM) on severe accident modelling of existing Light Water Reactors. This was considered urgent and necessary although FANGS contributed to the development of nuclear reactor types with which severe accident types with core melt could actually be excluded.

3. Description of the Action

- Clients and Stakeholders

Inside the European Commission:

- Energy and Transport (DG TREN, now ENER)
- Research (DG RTD)

Outside the European Commission:

- Generation IV International Forum (GIF)
- Sustainable Nuclear Energy Technology Platform (SNETP)
- International Atomic Energy Agency (IAEA)
- Nuclear Energy Agency (OECD/NEA)
- various Technical Support Organizations (TSO): IRSN, GRS
- Competitive Action consortia (several): all big players in nuclear energy including industry, research organizations and universities, (e.g. CEA, AREVA, KIT, FZJ, Pisa University etc.); and increasingly end-user industries for nuclear process heat.
- PBMR (Pty) Ltd, South Africa
- US DOE Laboratories: Oak Ridge National Laboratory, Idaho National Laboratory, Argonne National Laboratory, USA
- AECL, Canada
- Tsinghua University, China
- International Atomic Energy Agency (IAEA)
- European standardization labs: LNE, NPL, PTB
- Thermocoax
- French Atomic Energy Commission CEA
- Israel Atomic Energy Commission (IAEC)

- Major Objectives, deliverables and impacts

(1) Fuel and Component Tests

For most next generation reactor concepts, the feasibility and performance of reactor fuel is a key feasibility issue and on the critical path towards licensing, demonstration and deployment. Focus is given to fast reactor/transmutation fuel and high temperature reactor fuel, for which several successful irradiation tests in the HFR Petten are underway and/or in the planning. The technology for such irradiations is planned to be transferred to the SAFARI-1 reactor in South Africa subject to a contract with NECSA. The activity is completed with a database and a new task on high temperature instrumentation.

(2) Evaluation of feasibility, safety and performance of next generation nuclear reactors and fuel cycles

These analytical desktop studies assess various next generation nuclear reactors from a system point of view which is expected to provide sufficient information for a comparative system assessment. Work encompasses nuclear physics, thermal-hydraulics and thermal-mechanics analysis with focus on performance and safety. It reduces the required experimental effort and R&D for adequate demonstration. Scenario studies are included to identify the potential and limits of various nuclear growth scenarios with respect to bottlenecks (e.g. in fabrication) and resources.

(3) Contributions to European and International Collaboration

Development of a next generation nuclear energy system is too complex and expensive a task to be tackled by a single country alone. International cooperation is a necessity. The action aims at supporting existing cooperation frameworks and catalysing new collaboration with the objective of demonstrating one or several next generation nuclear energy systems which are compatible with the targets of the SET Plan. Examples for such activities are international networking within the High Temperature Reactor Technology Network, collaboration with IAEA/INPRO and with the Generation IV International Forum.

3.3. Major Highlight(s)

Highlights 2007

1. **The invention of a novel power conversion method** (superheating of reactor outlet fluid with compression heat pumps) producing very high temperature without imposing these high temperatures on the reactor itself were presented at two large conferences and have triggered interest of several industrials. This technique shortens the lead times, reduces R&D requirements and enables the use of nuclear process heat applications (e.g. thermochemical H_2 production) in a much shorter term.
2. **Nuclear process heat applications** (as opposed to electricity) in existing industry branches (e.g. refineries or chemical plants) were identified as a major pathway towards meeting the SET Plan objectives in the near-term. This has triggered the elaboration within HTR-TN of a dedicated project on coupling a nuclear heat source to an industrial end-user (EUROPAIRS, kick-off in September 2009).
3. In 2006 and 2007, the AMALIA laboratory was upgraded to cover **aqueous corrosion and stress corrosion cracking in supercritical water** reactor operating conditions (T_{max} = 650^{0}C, p_{max} = 360 bar). Two recirculation water loops

with full water chemistry control were commissioned, equipped with high pressure autoclaves for fracture mechanics, slow strain-rate tensile, and general corrosion testing. In 2008 the laboratory was further upgraded by commissioning a contact electrical resistivity measurement facility for corrosion kinetics studies.

Highlights 2008

1. Between 2006 and 2008, a major test campaign for the assessment of **carburization effects in HTR primary circuit** environments on turbine and heat exchanger (U720, CM247 and In792), and vessel (P91 parent material, X-welds and weld material) materials was undertaken. In this investigation, creep and fatigue specimens were exposed for 1000 h at 950^0C in a 1.6 bar absolute Argon + 2% CH_4 environment, followed by uni-axial creep tests at 750°C and 850°C, and low cycle fatigue (LCF) tests at 650°C on the as-received and the carburized materials. For reference, additional decarburization and thermal ageing treatments were conducted, and the materials creep and LCF tested. The carburization treatment caused a marked loss of creep strength and increase in minimum creep rate with respect to the as-received condition. The carburization treatment had a detrimental effect also on the LCF performances in particular at high strain ranges and low numbers of cycles to failure. The loss in creep strength is mainly associated with grain growth, micro-cracking and most importantly, with the dissolution of the tertiary and coarsening of the secondary g' particles. The LCF strength loss at high strains is associated with micro-cracking and growth at carbide boundaries, while at low strains it is mainly due to crack initiation at corrosion pits formed at the outer surface.
2. **Materials Workshop:** On 17-18 April 2008, the workshop on "Mechanical Testing for Next Generation Nuclear Systems" held at JRC-IE Petten attracted more than 70 participants from 20 countries. Noting that the development of innovative nuclear reactors critically depends on the availability of advanced engineering materials systems which have to withstand extreme conditions (high temperatures, intense neutron irradiation, and strongly corrosive environments, in combination with complex loading states and cyclic loading histories), the workshop specifically addressed the methodologies for mechanical performance and reliability assessment of nuclear materials in the proper environments during service and off-normal conditions. The programme of the workshop consisted of invited Keynote Lectures to set the scene, and contributed papers presented as posters. The quality of the presentations was excellent throughout, and ample time was devoted for lively discussions. According to the very positive feedback received from the delegates of research institutes and industry, the workshop was a great success. Also the High Temperature Mechanical Testing Committee of the European Structural Integrity Society, under the auspices of which the workshop was held, congratulated JRC-IE for the organisation of this first of a kind event which was gratefully received by scientists and engineers having a specific interest in the measurement of mechanical property data under extreme environments.

3. **HTR 2008 conference:** This series of highly successful conferences launched by JRC- IE in 2002 in Petten was followed by Beijing (2004), Johannesburg (2006) and Washington DC (2008). Since its beginning, the conference has attracted a growing number of participants in excess of 500 and has received again strong media coverage. FANGS supplies the permanent co-chair of the International

Organizing Committee, co-chair of the fuel track and chairman of a session. We have reviewed more than 30 papers out of a total of 220 presented and have both presented technical papers and co-authored several others. In the light of the current controversy of Cs release from HTR fuel, our results on HTR fuel irradiations in the HFR Petten were particularly appreciated. Apart from the excellent organization, high quality papers, posters and presentations (total 220, thereof 7 from JRC) were delivered due to strict reviewing. The best papers per track were shortlisted for publication in Nuclear Engineering and Design. The next conference will be held in October 2010 in Prague and will mobilize all partners of the European High Temperature Reactor Technology Network HTR-TN. The local organizing committee will be chaired by NRI Rez.

4. Neutron physics studies demonstrated that existing CANDU reactors can be used for implementing the **thorium-uranium fuel cycle,** for which large indigenous reserves are available in Europe and other countries. This makes CANDU reactors the currently most attractive short-term concept for conversion to supercritical water as a coolant, thus substantially raising power conversion efficiency. Also, CANDU reactors using pressure tubes avoid the costs and risks associated to manufacturing large reactor pressure vessels and manufacturing capability for supercritical water conditions.

Highlights 2009

1. **Nuclear waste minimization:** The HELIOS irradiation for testing different americium-bearing transmutation fuels in the HFR has been successfully started on 29 April 2009 and is planned to be carried out for 10 reactor cycles (~280 full power days). The start-up is the result of several years of preparatory work. The irradiation targets comprise U-free fuels and targets for americium transmutation with the aim to investigate fuel performance and helium release using different fuel microstructures and irradiation temperatures.
2. Kick-off of **EUROPAIRS project** (cf. highlight in 2007). Nuclear process heat applications require the collocation of a nuclear island with an industrial end-user. For the first time, EUROPAIRS gathers experts from nuclear industry, end-user industry and licensing authorities to develop a common approach to demonstrate the technical and economic viability of this concept. The action was strongly involved in the preparation of EUROPAIRS and in building this multidisciplinary consortium.
3. After having obtained green light from DG TREN for **creation of a new industrial initiative on nuclear cogeneration** as a SET Plan implementation tool, efforts are currently ongoing to provide the necessary documentation to establish this industrial initiative. Representatives of HTR-TN (incl. JRC-IET) presented the potential of Nuclear Cogeneration to achieving the SET Plan targets to the **President of the European Parliament** (J. Buzek) and to the **ITRE Committee** of the EU Parliament in 2008 and 2009, as well as to the **Polish Senate** in 2009.
4. Significant editorial contributions to the Strategic Research Agenda of the European Sustainable Nuclear Energy Technology Platform, a guideline for future nuclear R&D widely agreed with all stakeholders.

Highlights 2010

1. **International cooperation and joint programming**

- SNETP: cooperation with ESNII (fast reactors) and construction of NC2I (nuclear cogeneration) as third pillar
- HTR-TN: competitive projects: RAPHAEL completed, EUROPAIRS continued, ARCHER and CARBOWASTE proposals constructed
- Organization of HTR 2010 conference in Prague
- Euratom representation in GIF (VHTR Steering Committee, Fuel and Fuel Cycle and Materials PMB, Risk and Safety Working Group)
- IAEA: participation in INPRO Steering Committee

2. **Fuel and component tests**

- Two fuel irradiation experiments in HFR completed: HFR-EU1 and HELIOS
- Upgrading, development and qualification of experimental analytics: gamma spectrometry for in-pile tests in HFR, X-ray tomography, safety instrumentation

3. **Lead-cooled Fast Reactor: safety and feasibility assessment (competitive projects ELSY (-2010) and LEADER)**

- Core design and performance (e.g. for nuclear waste minimization)
- Safety and transient analysis: accident initiators, design basis conditions, e.g.: CFD study on sub-channel blockage (determination of “grace time”), vapour bubble transport
- Development of severe accident analysis capability
- Identification of R&D requirements
- Subcontract to KIT (KALLA lab): experimental steam-Pb interaction

Highlights 2011

1. **Support to SNETP**

- Presentation of the SNETP/NC2I Concept Paper for a new European Industrial Initiative at SET Plan conference in Warsaw. Preparation and scientific coordination of competitive actions as well as running the network HTR-TN (High Temperature Reactor Technology Network).
- Support to DG ENER and DG RTD: develop, catalyse and support strategies for development/demonstration/ deployment of next generation nuclear (electric and non-electric applications). Cooperate with ESNII (Fast Reactors) and develop NC2I (Nuclear Cogeneration).
- In support of DG ENER, participation in ENEF Working Group “Opportunities” to ensure close contact to industrial decision makers.

2. **Coordination of Euratom Contributions to GIF Projects**

- Support JRC duties as Implementing Agent for Euratom in GIF: coordinate Euratom contributions to GIF projects.
- Representation of EURATOM in GIF:
    - VHTR System Steering Committee
    - VHTR Fuel & Fuel Cycle Project
    - VHTR Materials Project (Metals)

    - Risk and Safety Working Group
    - (System Integration and Assessment projects as they become operational)
- Facilitate international cooperation within GIF, IAEA projects, with TSOs
- Networking incl. strategic road mapping, building and monitoring of new competitive projects
- Participation in conference committees and in editorial board of Elsevier Journal Nuclear Engineering and Design.

3. Safety and Feasibility Research

- Following the Fukushima accident, close cooperation with IAEA for development and application of nuclear safety standards for innovative reactors. Started development of common European safety assessment methodologies and evaluation tools together with EU TSO and with industry partners.
- Assessed and improved various reactor systems in terms of safety, including neutronics and thermal-hydraulics, feasibility and adequacy of safety concepts and margins:
    - Accident analyses, including design and beyond design basis accidents, source term determination and assessment of severe plant conditions to assess the adequacy of design safety provisions
    - Core design analysis incorporating issues of sustainability such as breeding and minor actinide burning performance;
    - Determination of operational safety parameters which need to be complied with for safe and reliable operation

4. Further Information

The FANGS action fully complied with the SNETP strategy and undertook nuclear safety related R&D to support decision making needed for the successful deployment of the advanced reactor concepts considered under SNETP.
FANGS relied on well-established and recognized existing infrastructures and analytical expertise at JRC-IET including irradiation testing, various laboratory test facilities and a range of analytical tools in the areas of reactor physics, thermal-hydraulics, thermal-mechanics, system codes and severe accident analysis including the associated user expertise and IT hardware. Several activities had a long-term character due to the involvement of heavy nuclear experimental installations. They produced valuable and rare scientific and technical results, although at a rather slow pace.

4.1. Integration and Networking

Most work was conducted within recognized European and international cooperation frameworks including competitive FP6 and FP7 projects. With this respect, the action's contributions to European networking (in particular through the productive High Temperature Reactor Technology Network operated by JRC-IET, in the fast reactor and transmutation community and in materials research) were instrumental for the definition and participation in several competitive projects on next generation nuclear energy and its applications. Those projects, in turn, were used as input to

major international initiatives such as GIF and INPRO.
Several bilateral cooperation agreements were used with non-EU partners (China, South Africa, US, Israel).
In several cases, JRC-ITU and JRC-IET shared work in competitive projects related to fast reactor and transmutation fuel (ITU: fuel production / IET: fuel irradiation) as well as in the area of high temperature reactor fuel (IET: irradiation / ITU: post-irradiation examinations and safety tests). There was also efficient cooperation on a small but fundamental exploratory research project.
Within JRC-IET, cross-unit cooperation topics concerned the feasibility analysis of nuclear-assisted in-situ coal gasification (with F.2) as well as stronger commitment to implementation of the SET Plan objectives (with F.6).
Within the unit F.4 itself, there was daily interaction with the actions MATTINO to exchange feed-back on evolutions in reactor design and material capabilities, and with CAPTURE for dissemination of results and training purposes.

4.2 List of Competitive Activities

FANGS was very significantly involved in the preparation, management and scientific-technical performance of related competitive FP projects:

FP5:

- High Temperature Reactor Fuel and Materials: HTR-F/F1, HTR-M/M1

FP6:

- Construction of EU nuclear technology platform: SNF-TP
- Materials for Gen IV reactors, nuclear H_2 production and transmutation: ExtreMat, GETMAT, HyCycleS
- High Temperature Reactor Technology, Fuel Cycle and Waste Management: RAPHAEL, PUMA, CARBOWASTE
- Lead-cooled Fast Reactor: ELSY
- Gas-cooled Fast Reactor: GCFR
- Supercritical Water Reactor: HPLWR
- Sodium-cooled Fast Reactor: EISOFAR
- Nuclear Waste Minimization: EUROTRANS

FP7

- Nuclear cogeneration of heat and power: EUROPAIRS
- High Temperature Reactor: ARCHER
- Lead-cooled Fast Reactor: LEADER
- Sodium-cooled Fast Reactor: ESFR
- Nuclear Waste Minimization: FAIRFUELS

In addition, until its termination FANGS has very actively contributed to the preparation of a significant number of competitive FP7 projects which were accepted after 2011 and to others which were not successful.

4.3. Mobility and training of researchers

FANGS employed one PhD student (defence in 2009) on Sustainability and Efficiency

Improvements of High Temperature Reactors covering experimental work on fuel irradiation tests including related fission gas release modelling, as well as analytical design studies on fuel and power conversion systems to reduce the constraints on the fuel. Those are achieved by a modified fuel design and by a novel power conversion system.
FANGS regularly presented lectures and co-organized workshops and internal seminars, mostly in the frame of competitive projects (e.g. the annual topical "Eurocourses" organized within the FP6 RAPHAEL project), but also as internal seminars.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2013

Action *52303 CAPTURE*
Action Leader: *Ulrik VON ESTORFF F04*

Authorising Officer: *Peter HÄHNER F04*
Leading Institute: *Institute for Energy and Transport*

0. Policy Area

Policy Theme: 5. EURATOM programme
Agenda N° & Title: 5.2 Nuclear Safety
Sub-agenda N° & Title: 5.2.3 Safe Operation of Advanced Nuclear Energy Systems

1. Rationale of the Action:

According to the common vision of major stakeholders from industry, policy and research, nuclear energy generation, provided nuclear safety is ensured, will continue to provide an important contribution to the security and competitiveness of energy supply in the EU, and the abatement of greenhouse gas emissions in line with the Strategic Energy Technology Plan (SET Plan) targets, and therefore remain a candidate for a sustainable energy mix. To translate that vision into concrete steps, the Sustainable Nuclear Energy Technology Platform (SNETP) has been created to develop a Strategic Research Agenda (SRA, 2009) summarising the most urgent research topics to be addressed, and to derive a Deployment Strategy (DS, 2010) identifying key actions for the implementation within a time horizon up to 2050.

Additionally, the European Nuclear Energy Forum (ENEF) was founded in 2007, which is a unique platform for a broad discussion on transparency issues as well as the opportunities and risks of nuclear energy.

Both nuclear stakeholder platforms (SNETP and ENEF) have working groups on Knowledge Management, Education and Training issues, which are pointing to possible risks in that area.

Due to the gradual retirement of staff from old nuclear power plants (NPPs), the EU Plan “Towards a new Energy Strategy for Europe 2011-20” puts great emphasis on the need for investments in new technologies, infrastructure, efficiency improvement, public education and skills. This is a condition for maintaining a strong nuclear contribution to low-carbon power generation.

The Council Conclusion of 1-2 December 2008 on the preservation of nuclear skills in the EU and the Council Directive from 23 June 2009 establishing the Community Framework for nuclear safety are drivers for the WP of CAPTURE.

Additionally, in the Communication to the European Parliament and the Council from 16 September 2011 the Commission stresses that all opportunities and options should be used to guarantee that sufficient knowledgeable personnel is and will be available to the sector, including industry and government oversight bodies. The Communication puts the European Human Resource Observatory in the Nuclear Energy Sector (EHRO-N), which was developed in CAPTURE and launched officially in 2011, in a central role as information source.

The Recommendation of the EP and the Council of 18 June 2009 on the establishment of a European Credit System for Vocational Education and Training (ECVET) (2009/C 155/02) is the basis for the inclusion of the nuclear competences and skills thesaurus harmonisation in the CAPTURE work program.

Finally, the upcoming Communication on “The EU’s demographic challenges and ensuring growth and cohesion” confirms that efforts have to be undertaken in order to guarantee a safe harvesting of nuclear energy.

More specifically, it can be stated, that the experts who took part in design and commissioning of most NPPs decades ago are gradually disappearing from an active role. Knowledge on the original designs, and related technology and procedures, as well as scientific background knowledge are endangered to be lost in a few years to come, if not partly lost already, through a generation gap formed in the supply of

nuclear experts. In addition to the nuclear knowledge accrued in each Member State, JRC has also produced a long standing record of results from its own institutional activities and even more through its participation in a large number of European Nuclear Network partnership projects.
The CAPTURE action is addressing not only Knowledge Management, Knowledge Preservation, Education and Training in the nuclear energy sector, but analyses also human resources and skills and competences in the sustainable energy sector.
The use of innovative tools and mechanisms for intelligent knowledge management is indispensable for achieving the CAPTURE goals. CAPTURE has significantly contributed to the JRC activities dedicated to ensuring that the European leading scientific position in the global nuclear power know-how is preserved and reinforced.

2. History and development of the Action:

The Action CAPTURE was developed within the Action SAFELIFE during the second half of 2007 and became a standalone Action in 2008.

3. Description of the Action

CAPTURE is built on three pillars, namely 1) Evaluation of Human Resources Trends in the Sustainable Energy Sector, 2) Harmonization of nuclear skills and competences with EU-27 wide recognition, 3) Contribution to Nuclear Education, Training and Knowledge Management (including preservation and dissemination)
1) Human Resources Trends in the Sustainable Energy Sector
In order to determine the situation of nuclear-educated human resources in Europe (i.e. supply and demand), assess the trends and suggest policy options for improvement, the European Human Resources Observatory in the Nuclear Energy Sector (EHRO-N) has been set-up in support to DG ENER. The main objective of this observatory is to provide a central point for collection of data and trend analyses on issues related to development and preservation of nuclear human resources and nuclear safety expertise in the EU. This is even more important, considering the possible lack of interest to study nuclear subjects after the Fukushima accident. Since its launch in 2011 EHRO-N has become a widely recognized and appreciated instrument. The experience and competence gained in EHRO-N was recognized and will be used as role model for the sustainable energy sector. Specifically, the different sustainable energy fields in the SET-PLAN E&T Core Group can benefit from the experience of EHRO-N and apply the lessons learnt directly to their fields. A common EU-27 view of the situation of sustainable energy related human resources supply and demand can serve as a strong instrument to anticipate any gaps.

2) EU wide recognized and harmonized nuclear competences and skills
The IET facilitates the harmonization and standardization of nuclear skills recognition within the EU-27, in support to DG RTD and DG EAC. Therefore, the implementation of the ECVET principle in the nuclear energy sector has been continuously and proactively supported, under direct guidance of DG EAC's CEDEFOP, in charge of ECVET implementation. This is as well strengthening the first pillar "EHRO-N", as it facilitates the analysis of the supply/demand gap in the nuclear energy sector. The ultimate objective after full implementation of ECVET, which may go beyond 2015, will be an enhanced mobility of the nuclear workforce within the EU-27, while mainly two tasks have been addressed in WP2013: 1) to create an open database taxonomy of

commonly recognized nuclear skills and competences, 2) to support the implementation of the ECVET system in the nuclear energy sector.

3) Contribution to Nuclear Education, Training and Knowledge Management
To remain a recognized international KM player in nuclear safety knowledge management in the EU, four types of activities have been carried out by IET: 1) to preserve and maintain IET-related nuclear safety knowledge, 2) to contribute to the Initiative "Information and Training on Nuclear Safety" proposed by DG RTD upon request of Commissioner Geoghegan Quinn, 3) to create modern nuclear training initiatives in IET-related nuclear safety competence areas, 4) to collaborate with the IAEA on nuclear safety KM issues through the Practical Arrangement..
Training and education material specific to the scientific expertise of the IET has been developed for the use in academic organisations such as the European Nuclear Education Network (ENEN), National Universities, etc. In this respect, the JRC has drafted a MoU with the ENEN.
The IET web-portal ODIN and the recently created webpage of CAPTURE are used to manage and maintain the reference data, EUR- and State-of-the-Art reports, which are available or progressively consolidated in specific workshops through a dedicated method developed at the IET for consolidation of knowledge.
Jointly with ENEN and in the frame of the EN3S, the IET has contributed as well to the FP7 Co-ordination Action of 4 year duration for an Information and Training programme regarding lessons drawing from the Fukushima accident, on initiative of EU Commissioner for Research and Innovation. The Action contributes to maintaining, consolidating and transferring the knowledge in nuclear technology and design in support to DG RTD FP7 relevant projects and the IAEA. To underpin this work the CAPTURE action has promoted the creation and dissemination of comprehensive sources of reliable nuclear information, such as consolidated EUR reports, a publicly accessible web-portal, multi-media trainings, etc.
Collaboration is ongoing with the IAEA Nuclear Knowledge Management Department. In this frame contributions to the various IAEA Knowledge Management Guidelines will be provided.

3.1. Clients and Stakeholders

DG RTD
DG ENER
DG EAC
DG ELARG
IAEA
OECD/NEA
Nuclear Industry
Nuclear Regulators

3.2. Major Objectives, deliverables and impacts

Objective: *Policy Support to DG EAC/RTD within the European Credit System for Vocational Education and Training (ECVET) initiative for a pilot project on mutual recognition of nuclear qualifications in Europe*
Impact: Through the bundling of forces between DG EAC, RTD and JRC the nuclear energy community has reached a much better understanding of the ECVET principles

and its need for implementation. The technical support for the implementation of ECVET (agreed in the Copenhagen declaration) in the Education and Training sector of the EU Member States is highly appreciated by the European stakeholders in the nuclear energy sector, as there is not yet enough progress made at National level. This activity is well in line with the subsidiarity principle.

Description: DG EAC is responsible for the implementation of ECVET in the EU Member States in all areas of vocational training, entering also partly in academic education. As agreed between DG EAC and JRC, the JRC supports ECVET implementation in the nuclear energy sector.

JRC provides seminars and tools for the nuclear energy sector to facilitate ECVET implementation and develops a harmonized (between different stakeholders from different MS) job taxonomy for the professions in nuclear design, operation and decommissioning based on the knowledge, skills and competence framework.

Through the complete implementation of ECVET in all sectors (not only the nuclear energy one) a better mobility of workers (through harmonized recognition of learning outcomes, based on knowledge, skills and competences) is enabled and leads to an improved competitiveness for the EU.

Scientific Outputs:

Current use of ECVET in the nuclear industry sector of the EU-28; JRC85231;

Guide for nuclear ECVET Providers - Information and helpful templates; JRC85598;

Towards the implementation of the European Credit System for Vocational Education and Training (ECVET) in the nuclear energy sector JRC85564

Objective: *Policy Support to DG RTD within the Initiative of SET-PLAN as Operating Agent for the European Human Resource Observatory in the Sustainable Energy Field*

Impact: The lessons learnt from the operation of EHRO-N in the nuclear energy sector are passed to the Sustainable Energy Technology Platform SET-Plan, which led to more efficiency in the process of establishing a SET-Plan Roadmap on Education and Training.

Description: The JRC participates to two out of 13 working groups on Education and Training within SET-PLAN. It also contributes to the final assessment reports of the working groups: the education and training working group on nuclear energy and the education and training working group on horizontal issues.

All outputs from the 13 working groups are consolidated into a SET Plan Roadmap on Education and Training. The JRC provided input to areas of its competence, i.e. nuclear energy, and by consolidating the Roadmap based on its expertise from operating EHRO-N in the nuclear energy sector.

Scientific Outputs:

SET-plan Education and Training Initiative: FINAL REPORT (revised): October 29, 2012: Working Group 13: Horizontal Field 2 - Coordination of Education and Training Systems; JRC77326

Strategic Energy Technology (SET) Plan - Roadmap on Education and Training; JRC85088;

SET-Plan European Energy Education and Training Initiative: WG Nuclear Energy: Final Assessment Report; JRC77178

Objective: *Policy Support to DG ENER within the ENEF initiative as Operating Agent for EHRO-N, the European Human Resources Observatory in the Nuclear Energy Sector*

Impact: By monitoring the supply and demand of the nuclear energy workforce at member states level, the action, as possible future shortcomings related to the nuclear workforce are detected in advance therefore contributing directly to Nuclear Safety on the long run.
Description: The European Human Resource Observatory in the nuclear energy sector (EHRO-N) was set up on the request of DG ENER (kicked-off by an administrative arrangement with DG ENER and now incorporated into the JRC institutional work program) in the frame of the European nuclear energy stakeholder forum ENEF. The Observatory monitors constantly the supply and demand of the nuclear energy workforce, presenting the results and receiving the guidelines to/from the Senior Advisory Group, which is composed of more than 30 representatives from different geographical and sectorial backgrounds related to nuclear energy. As Operating Agent of EHRO-N, JRC is responsible for the day-to-day management and the carrying out of project studies following the subsidiarity principle.
Scientific Outputs:
EHRO-N 2013 Annual Activity Report; JRC85305;
Top-down workforce demand extrapolation from nuclear energy scenarios; JRC81666

3.3. Major Highlight(s)

In 2008 the JRC-IET developed Consolidation Methodology was applied to the Russian-type WWER Reactor Pressure Vessel Embrittlement Knowledge, with the aim of coming up with a consolidated State-of-the Art Review in 2009 and with qualified educational and training material in 2010.

In 2009 a 1-week training course was designed and held on Next Generation Nuclear Reactors. The Action received also a spin-off through the ENEF (European Nuclear Energy Forum) Working Group Risk/Sub-working Group Education and Training. On request of ENEF and DG ENER a European Nuclear Human Resource Observatory was prepared to be hosted by the JRC within the Action CAPTURE. The main objective of this observatory is to provide a central point for collection and trend analyses on issues related to development and preservation of nuclear human resources and nuclear safety expertise in Europe.

In 2010 the nuclear stakeholders in Europe regarding Supply and Demand of Human Resources were mapped within the European Human Resource Observatory in the nuclear energy sector EHRO-N. The Knowledge Preservation activities were disseminated through the CAPTURE website.

In 2011 the first trend analysis for supply and demand of nuclear human resources was presented through EHRO-N based on its bottom-up survey. A major contribution was also given to the Communication from the Commission (requested by DG ENER) to the Council and the Parliament on the European Education and Training activities in the Nuclear Energy Field in the EU.

In 2012 the database on a common language for employment and education/training related to nuclear fission (i. e. a common "taxonomy" for skills and competencies linked to jobs) was developed.

Support was also given to the Consolidation of the Euratom contribution to GIF regarding development, maintenance and management of the EUROGIF website and databases and annual report on EURATOM contribution to GENIV.

In 2013 EHRO-N issued a report on the Modelling of HR Needs in the Nuclear Energy Sector based on different Energy Scenarios. Additionally, first preliminary trends were presented after an analysis of the pre- and post-Fukushima student enrolments in nuclear engineering subjects.

4. Further Information

4.1. Integration and Networking

As a novelty for the JRC the Action CAPTURE has integrated education and training activities from two Institutes, namely the IET and the IRMM in the nuclear safety area in 2009 as a trial for a collaboration across Institutes. It was maintained for some time, but then stopped for 2013 due to administrative shortcomings. There has also been close co-operation with the ITU in setting up the European Nuclear Safety and Security School (EN3S).The two nuclear fora where KM, Education and Training are discussed are the European Nuclear Energy Forum (ENEF), set-up by DG ENER and the Sustainable Nuclear Energy Technology Platform (SNE-TP), set-up by DG RTD. As nuclear is also a part of the SET-PLAN, CAPTURE contributed as well to their E&T related working groups. The EC-external main active players in the field of Nuclear Knowledge Management are the IAEA and the OECD/NEA, with who also close co-operation has been established, in order to avoid duplication. As well Foratom and the European Nuclear Society have strong links with the CAPTURE Action.

4.2 List of Competitive Activities

The Action CAPTURE took part in the formulation of several competitive project proposals, of which CAPTURE staff participated successfully to the following: STYLE, CORONA, SERES, CESAM, GENTLE, NULIFE. Additionally, an administrative arrangement between JRC and DG ENER was signed, for a value of 150 k€ for Database, Website development support to DG ENER for the Nuclear Human Resource Observatory.

4.3. Mobility and training of researchers

The CAPTURE Action hosted three trainees and designed multimedia training courses for students and young professionals in the nuclear field.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2013

Action 52304 MATTINO: MATerials performance assessmenT for INnOvative reactor systems

Action Leader: Peter HÄHNER, January 2009 – July 2011
Karl-Fredrik NILSSON, July 2011-December 2013

Authorising Officer: Vesselina RANGUELOVA (January 2009 – July 2011),
Peter HÄHNER (July 2011- December 2013)

Leading Institute: Institute for Energy and Transport

0. Policy Area

FP7 Policy Theme: 5 The EURATOM programme

Agenda No & Title: 5.2 Nuclear safety

Sub-Agenda No & Title: 5.2.3 Safe Operation of Advanced Nuclear Energy System

1. Rationale of the Action:

Nuclear energy provides an important contribution to the security and competitiveness of low carbon energy supply in line with the Strategic Energy Technology Plan (SET-Plan) targets. To translate this into concrete steps, the Sustainable Nuclear Energy Technology Platform (SNETP) has developed a Strategic Research Agenda and a Deployment Strategy for a time horizon up to 2050. It consists of three pillars: i) plant life management and license extension of present light-water reactors (LWR) and construction of new light water reactors (LWR) with evolutionary designs; ii) development and deployment of innovative fast neutron reactors with closed fuel cycles, and; iii) non-electric applications, primarily high temperature reactors for process heat and co-generation. The performance of materials and the integrity of the mechanical components under the relevant operational conditions are central to the safety, performance and cost for all types of nuclear reactors.

There is a need for increased harmonization of licensing and design, assessment and test procedures and integration of the national research programs to reach cost efficiency and acceleration of the technology development and implementation. This is addressed by SNETP and the associated platforms. JRC has an important role to play as scientific reference centre and as a partner free of national and commercial interests and with a mission to support European policy making.

The safe operation of nuclear power plants requires ageing management programs for safety related components to control and mitigate the effects of ageing. This necessitates research on materials degradation and structural integrity of nuclear power plant components. The R&D work for present and evolutionary designs of light-water reactors is done in the network NUGENIA where JRC is an active member.

The next generation of nuclear power plants (Generation IV) will minimize its radioactive waste and use the uranium much more efficiently. These reactors are based on fast neutrons with sodium (SFR), lead (LFR) or helium (GFR) as coolant and are expected to be commercially available from 2040. A European industrial initiative (ESNII) to design and construct such reactors was launched in 2010. The design life will be at least 60 years, which in combination with higher temperatures and burn-up as well as corrosive coolant environment, give rise to R&D challenges for materials and components that require innovative solutions. Materials that are commercially available today (e.g. austenitic steels and ferritic martensitic steels) need to be qualified for the more severe conditions but new classes of materials also need to be further developed and qualified e.g. ODS steels and composite materials such as Silicon Carbides (SiC). The data obtained during the qualification procedure then need to be translated into new design codes. The EERA Joint Programme on Nuclear Materials (JPNM) supports ESNII on the materials and components issues. JRC is a key partner in both ESNII and EERA JPNM.

2. History and development of the Action:

MATTINO was launched in January 2009, in order to focus IE's structural materials research efforts on GenIV applications. The first year was a transition period as also tasks inherited from the discontinued actions SAFELIFE and SAFECASK were pursued, and the labs were adapted to new testing needs (higher temperature, miniaturized testing, etc.). As a consequence of the Fukushima accident the nuclear research at IET was re-organized. More emphasis was given to severe accident and all nuclear materials related research in the Actions POS (52103) and FANGS (52302) was transformed to MATTINO. From 2012 MATTER therefore addressed material and structural integrity issues related to present and future reactors and linked to all three pillars of SNETP. In the first two years the Action focused on material characterization and more basic research but for the last years, emphasis shifted more towards Codes and Standards. The networks ESNII, NUGENIA, NC2I and EERA JPNM were all launched in 2010/2011 and the bulk of the work in the last three years was associated with at least one of these networks. The description of the Action below refers mainly to the situation after 2011.

3. Description of the Action

The R&D work in MATTINO is closely integrated with the SNETP Networks, in particular NUGENIA for light water reactors and the EERA Joint Programme on Nuclear Materials but also with the industrial initiatives ESNII Systems and co-generation (NC2I). The work program was designed to strike a proper balance between research into experimental materials performance assessment and the need for JRC to provide a European reference function through the execution of pre-normative R&D and the participation in Materials Codes and Standards development. MATTINO covered the following range of multi-annual R&D topics to support long-term EU policy needs and to ensure JRC competences in nuclear safety technology for all reactor types of relevance for Europe:

- Advanced thermo-mechanical, corrosion resistance, and irradiation and environmental safety performance assessment of structural materials, incl. joints/welds taking into account high temperature coolant compatibility and long-term operation;
- Development of codes-of-practice for advanced non-standard thermo-mechanical, miniaturised specimen testing, and environmental testing; harmonisation of test methods, inspection procedures and data management tools applied in Europe; participation in round robins and input to standardisation bodies;
- Structural materials performance assessment under anticipated operational and accidental conditions for safety issues; input to material design codes and standards;
- Physically-based modelling with experimental validation to contribute to a better understanding of the materials performance in the respective conditions and environments.

Members of MATTINO were also active in the management and coordination of EERA JPNM, NUGENIA and NC2I. In addition to the more technical work MATTINO members were also active in supporting Policy DG's on issues such as the role of nuclear energy in a future low-carbon energy mix or revision of the nuclear safety directive.

- **Clients and Stakeholders**

Networks: NUGENIA, ESNII, NC2I, EERA JPNM
Technical Support Organizations: IRSN, GRS, VTT
International organizations: OECD/NEA, IAEA, GIF,
Standardization organizations: ISO, CEN/CENELEC, ISO, AFNOR
Industrial partners, utilities: e.g. EDF, Vattenfall, Fortum, EoN, Tractebel, Iberdrola)
Industrial partners, reactor designers, component and materials manufacturers: e.g. AREVA, ANSALDO, ALSTOM, ArcalorMittal, Skoda, Technacom, VUJE
European Commission Directorates: Research and Innovation (RTD), Energy (ENER), Enlargement (ELARG), Enterprise & Industry (ENTR)
Nuclear Research Centres : e,g, CEA, SCK•CEN, CIEMAT, CVR, NRG, NNL, RATEN, KIT, HZDR, ENEA, Jozef Stefan Institute,
Universities: Univ. of Manchester, Univ. of Oxford, KTH, Aalto University, Charles University, TU Braunschweig, Middle East Technical University, Delft University, University of Pisa

Major Objectives, deliverables and impacts

As mentioned above the objectives for MATTINO changed during the period due to the inclusion of POS and FANGS from 2012 and a shift from more basic research on material characterization to Design Rules and Standardization. The Deliverables of the Annual Work Program 2013 were defined under four objectives:

1. Structural Integrity Assessment Procedures in Support of Reactor Safety

The objective is to develop and validate assessment procedures for the safe operation of nuclear components with ultimate goal to be included as Standards or European best-practice procedures. These procedures are meant to be used for industrial applications. They should strike a balance between robustness, applicability to industrial applications and reduce unnecessary conservatisms. The work is done in close collaboration with the NUGENIA consortium for present reactors and with the EERA JPNM for future reactors. Specific areas include thermal fatigue, integrity of welded components and creep-fatigue degradation. The Deliverables are papers published in peer-reviewed articles or conference proceedings, project reports and contributions to consensus reports published by e.g. IAEA and CEN.

2. Pre-normative research: Procedures for Material Testing and Database

Procedures for Material Testing and Component Design. The research work under this objective comprises two activities: a) development of new tests methods which are not yet standardized (e.g. small punch testing, residual stress measurements)
b) performance of tests with objective to generate material data for assessment procedures and for calibration and validation of physics-based models
c) development of web-based material database and standards.

The deliverables include scientific articles, contribution to test standards and procedures, development of the technical systems and data management tools. MATTINO has validated the CWA 156627:2007 on the use of small punch testing for creep and tensile properties; undertaken the migration of the IAEA Surveillance database to MatDB (https://odin.jrc.ec.europa.eu); systems that allow interoperability of material databases, including between IE's MatDB and ORNL's GenIV Handbook; development of pneumatic bellows-based load system for material testing in corrosion loops. The work to integrate MatDB and the ORNL GenIV Handbook also served to validate the prenormative data formats for engineering materials developed in the context of CEN Workshops ELSSI-EMD and SERES.

3. Physics-based modelling and micro-structural analysis

Development of models and methods that address features and processes and different length and time scales integrated with supporting experiments and microstructural analysis to advance the understanding of material performance (e.g. deformation mechanisms, degradation processes) for materials and operating conditions, relevant to both present and future reactors. Two approaches are covered: a) multi-scale approach for developing understanding of elementary mechanisms and their evolution and b) engineering-level approach for developing tools applied to design and assessment of components. MATTINO staff have developed models based on strain gradient plasticity and implemented these models into commercial finite element codes. The research has been published in peer-reviewed articles and the methods are now being applied by the scientific community to understand features such as cyclic softening and stress corrosion.

4. Networking, Integration & Policy Support

MATISSE staff has contributed actively to SNETP and its related networks for accelerated integration of European nuclear safety research. In particular EERA JPNM, NUGENIA and NC2I, MATTINO staff have been leading subprograms or managing secretariat. Moreover MATTINO has provided support to policy DGs, in particular DG-ENER and RTD, and international organizations such as IAEA, NEA/OECD and GIF on nuclear safety with emphasis on materials and components and the role of nuclear energy in future low-carbon economy. The output includes strategic planning documents for the SNETP Networks, contributions to roadmaps on future energy policies for DG ENER and NEA, impact assessment for revised Nuclear Safety Directive for DG ENER, contribution to synthesis report on future priorities for EURATOM fission research. The main Scientific and Policy Support Documents are listed below.

3.3. Major Highlight(s)

The establishment of EERA Joint Program on Nuclear Materials

The EERA Joint Program on Nuclear Materials was launched at the SET-Plan Conference in November 2010.JRC-IET is leader of subprogram 1, 'Materials foe ESNII prototypes and demonstrators ', and member of its Management Board. EERA JPNM now has 19 full members and 12 associates representing 15 EU Member States and essentially all national laboratories for nuclear materials. EERA JPNM has been quite successful in fulfilling its two main objectives: integration of the nuclear

materials research in the Member States and provide underpinning scientific and technical support to the development, design and construction of sustainable nuclear energy reactor systems.

Development of Small Punch Test: A semi nondestructive material test method for miniature specimens

The amount of nuclear material available for testing is often very limited, e,g, irradiated materials, heat affected zone of a weld, material from in-situ components in a surveillance program. Due to the small volumes the specimens that can be made do not fulfill size requirements in test standards. There is therefore a need to develop test methods for miniature specimens for which the test data can be representative for real components. The small punch test where a small disk (diameter 8 mm and thickness 0.5 mm) is used is one of the most promising miniature tests. JRC-IET developed a CEN Workshop Agreement (pre-standard) in 2007 **(**CWA 156627:2007). During the reporting period, MATTINO staff has further developed and validated the small punch test for both tensile, creep and fracture properties and applied it to different materials including different zones of welds. JRC-IET is one of the most advanced research groups for small punch tests and the results have been reported in scientific articles and conference proceedings.

Development of web-based Materials Data Base (MatDB) for sharing of material data

Access to high quality data is crucial for the development and assessment of materials. Generate relevant data is very costly and time consuming. JRC-IET has therefore developed the web-based database and data assessment tool MatDB. In the reporting period, MatDB has served the data management needs of various EURATOM projects, such as GETMAT and MATTER. There exist different databases but usually they cannot be combined as the data structures are different. In the scope of an I-NERI project with ORNL, the feasibility of database interoperability was demonstrated using emerging technologies for engineering materials data. Given the crucial role of data in materials research, the need for citing and referencing data, or just a system increase the awareness of data sets, has been highlighted. To this end support for data citation introduced in MatDB, thereby promoting sharing, discovery, and reuse of research data. Data sharing is the most obvious step in an integration of the European nuclear materials research. The new developments of the MatDB will be an important tool for this purpose.

Development of bellows-based loads system for materials characterization in aggressive environments

MATTINO staff has together with VTT developed bellows-based pneumatic loading devices connected to remote control units. Such loading systems do not use moving parts, the design is very compact and can be used for different types of tests. This makes it ideal for testing in aggressive environments and hot cells. The bellows based systems have been implemented for testing of e.g. stress corrosion cracking in the loops for light-water and super-critical water conditions in the AMALIA laboratory. The systems have also been designed for liquid-lead loops and hot cells. Research based on the bellows-based systems has been reported in a number of scientific publications and conference proceedings. A description of the systems can be found in

JRC82204, P. Moilanen at al, *New applications of pneumatically powered testing equipment for extreme environments*, Baltica IX, International Conference on Life Management and Maintenance for Power Plants, Finland 2013.

Assessment procedures for thermal fatigue in nuclear components

Thermal fatigue is one of the most important degradation mechanisms in nuclear power plants. The assessment of thermal fatigue is difficult due to the complex loading and the intricate cracking patterns. In MATTINO simplified models based on the spectrum loading approach for engineering assessments to more advanced fracture mechanics models that also account for creep-fatigue interaction that may occur at higher temperatures. The results have been published in peer reviewed articles.

Development of crystal plasticity models for microstructural evolution

Constitutive properties and the microstructural evolution of materials are controlled by the processes and features at different length and time scales of the materials which is addressed by so-called physics-based models. In MATTINO crystal plasticity models that model individual grains of a metal have been developed and implemented into finite element codes. The models have been applied to for instance simulate stress corrosion cracking where cracks propagate along the grain boundaries. By including strain gradient effects the models have been used to explain the formation of areas with high concentrations of dislocations that evolve with the global deformation. The models and the results have been published in scientific journals.

4. Further Information

4.1. Integration and Networking

External collaborations exist through the participation in indirect actions that MATTINO contributes to and that are listed in Section 4.2, as well as through the following international cooperation and memberships:

SNETP. (www.snetp.eu)Sustainable Nuclear Energy Technology Platform. The MATTINO stag have contributed to the Strategic Research Agendas 2009 and the revision 2013.

- **NUGENIA**. (www.nugenia.org) is the Gen II/III pillar of SNETP. JRC is an honory member of NUGENIA. MATTINO staff is part of the NUGENIA secretariat and active contributor to Technical Area 4: Integrity assessment and ageing of systems, structures and components and Technical Area 8: In-service inspection and NDE.
- **ESNII:** www.snetp.eu/esnii/ is the fast reactor pillar of SNETP. MATTINO staff represents JRC in the ESNII Task Force.
- **EERA** (www.eera-jpnm.eu)European Energy Research Alliance, Joint Programme on Nuclear Materials. MATTINO staff is part of the Management board and leader for sub-programme 1.
- **NC2I**

GIF (www.gen-4.org **)**MATTINO staff have been active in the following subgroups:

CI) **VHTR** - Subgroup Metals and Design Methods

CII) **VHTR** - Subgroup Materials and Components
CIII) **SCWR** - Chemistry and Materials

IAEA MATTINO has contributed to the following Coordinated Research Projects:
CRP 12020 - "Development and applications of the technique of residual stress measurements in materials"
CRP 1488 - "Accelerator Simulation and Theoretical Modelling of Radiation Effects (SMoRE)"

NeT - Network on Neutron Techniques Standardisation for Structural Integrity. This Network is managed by MATTINO staff.

CEN/CENELEC: JRC has contributed to the CEN WS 64 on 'Design rules for innovative nuclear installations.

OECD/NEA MATTINO is a member of: Working group on Integrity and Ageing of Components and Structures and the Expert Group on Heavy Liquid Metal.

ENEF European Energy Nuclear Forum is a group led by DG-ENER for broad discussion among all relevant stakeholders on the opportunities and risks of nuclear energy: MATTINI is member of the ENEF Working group Opportunities.

Working groups on environmental degradation ICG-EAC - International Cooperative Group on Environmentally Assisted Cracking; **ECG-COMON -** International Group on Corrosion Monitoring
EFC-WP4 - European Federation of Corrosion Work Party IV Nuclear Corrosion; **IGRDM -** International Group on Radiation Damage of Materials

Hydrogen Embrittlement CoE: Cooperation Agreement Snecma - Volvo Aero - JRC

4.2 List of Competitive Activities

ExtreMat: New materials for extreme environments (cross-cutting nuclear and non-nuclear materials issues)
GETMAT: GEn IV and Transmutation MATerials (cross-cutting nuclear materials issues)
HPLWR 2: High Performance Light Water Reactor Phase 2 (WP on materials for SCWR)
RAPHAEL: ReActor for Process heat, Hydrogen And Electricity generation (WP on materials for VHTR)
HycycleS: Materials and components for Hydrogen by sulphur based thermo-chemical cycles (materials for a specific VHTR process heat application)
MATTER: MATerials TEsting and Rules
MULTIMETAL: Structural Performance of Multi-Metallic Components
ARCHER: Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D
STYLE: Structural integrity for lifetime management – non-RPV components
FAIRFUELS: Fabrication, Irradiation and Reprocessing of FUELS and targets for Transmutation
PELGRIMM: PELlets versus GRanulates: Irradiation, Manufacturing & Modelling
SCWR-FQT: Supercritical water cooled Reactors – Fuel Qualification Testing.

4.3. Mobility and training of researchers

MATTINO promotes the mobility and training of young researchers in the field of nuclear safety and security through the supervision of research activities tailored for trainees, PhD students and post- docs, in cooperation with various universities. Two staff members of the action hold university lecturing qualifications and associate professorships. The Action has typically had 2-3 Postdocs and one or two PhD students. During the period eight Ph.D. theses have been successfully defended under the auspice of the MATTINO Action. The MATTINO staff has given lecturers on creep and fatigue assessment at summer schools. JRC staff has also been the lead organizer international Workshops and conferences such as

- 5th International Topical Meeting on High Temperature Reactor Technology (HTR 2010), in Prague, Czech Republic,
- Joint European Commission (EC) and International Atomic Energy Agency (IAEA) Topical Meeting on ‘‘Development of new structural materials for advanced fission and fusion reactor systems”, 2009 in Barcelona, Spain and in 2012 in Ispra, Italy;
- First and second International Workshop on Physics-based Models and Experimental Verification organized 2012 in Ankara and 2013 in Antalya, Turkey.

EUROPEAN COMMISSION
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JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2011

Action *53101 – NuTraSeal: Nuclear Traceability and Sealing Systems*

Action Leader: *Francois Littmann E.08*

Authorising Officer: Willem Janssens (E.08-Nuclear Security Unit)

Leading Institute: *Institute for Transuranium Elements (ITU)*

0. Policy Area

Policy: 5. Euratom Programme,
Agenda 5.3. Nuclear Security,
Sub-agenda 5.3.1 Nuclear Safeguards, Additional Protocol and Combating Illicit Trafficking

1. Rationale of the Action:

Nuclear safeguards applications require highly specialized and secure systems for identification, sealing, tracing and tracking and, more in general, providing continuity of knowledge in safeguarded installations. New solutions and improved designs are continuously requested by the inspection authorities.
The European Commission DG ENER and the IAEA, within the framework of the EC Support Program, asked JRC to develop new sealing equipment, based on the patented JRC ultrasonic sealing system or electronic technologies, for underwater and dry storage in medium & long term repositories, to carry out vulnerability assessments and to develop new technologies to improve security in the safeguard domain.

2. History and development of the Action:

The SILab (Seals & Identification Laboratory) from the JRC provides support to DG ENER and IAEA in the form of R&D, prototype equipment, training, calibration and services. It assists them also for Vulnerability Assessment and tests on in-house products as well as commercially available or specially developed equipment in safeguards applications.
The specific tasks are agreed with the customer in the framework of the JRC-DG ENER co-operation agreement and in the framework of the EC Support Program (SP-1) with the IAEA, and are related to development and deployment of sealing and identification equipment,
One line of development is to further rationalize the ultrasonic sealing concept and apply it to new applications. DG ENER and IAEA have requested to develop systems for medium and long term dry storage containers which entail new design of seals and reading heads. Ultrasonic underwater bolt seals developed by JRC are in use:

- for CANDU spent fuel storage in Rumania (Cernavoda), Canada (Darlington) & Pakistan (Karachi)
- for other fuels in France (La Hague)

During the second part of the timeframe, new requests came from both DG ENER and IAEA to:

- develop seals for dry storage casks in Lithuania, using the ultrasonic technology coupled with optical fibre seals, in order to ease the inspection and provide real time alarm to headquarters.
- develop electronic low cost seal, with optical fibre loop.
- develop automated verification machines for copper brass seals.

3. Description of the Action

3.1. Clients and Stakeholders

Internal customer: DG ENER - EURATOM
External customer: IAEA (International Atomic Energy Agency)

3.2. Major Objectives, deliverables and impacts

Long-term indispensable/ essential support to implementation of EU policy or legislation

Objective 1: Design, testing, internal vulnerability assessment and commissioning of ultrasonic bolt seals for underwater application on CANDU spent fuel storage, including reading equipment and data transmission system.

Deliverables,

2007	- 2 reading heads with associated acquisition equipment and software (1 for operation by IAEA in Cernavoda unit 1 and 1 for Vulnerability Assessment by a third party laboratory). - 100 JRC Candu Seal seals (JCS) (50 for operation by IAEA and 50 for Vulnerability Assessment by a third party laboratory).
2008	- 50 JCS seals for operation by IAEA (competitive action) - 1 Reading-Head with associated acquisition equipment and software for operation in Cernavoda unit 2 for IAEA (competitive action)
2009	- 1 set of handling tools for operation by IAEA in Cernavoda unit 2 (competitive action) - First prototype of JKS System (JRC Kanupp Seal) available in JRC-Ispra for test.
2010	- JKS sealing system for operation by IAEA for Pakistan, Karachi derived from JCS system, 2 reading systems, 1 set of handling tools, 30 seals and 30 tie rods (competitive action) - Requested by DG ENER, for dual inspections in Cernavoda I & II, 2 reading systems, 75 JCS seals, end fittings for tools, training kit and operational support (AA)
2011	- JCS sealing system for operation by IAEA for Canada, Darlington, 2 reading systems, 250 seals (competitive action) - First training of inspectors in Ispra on the JKS system (2 IAEA inspectors) - For IAEA, 30 JKS seals and 30 tie rods for Pakistan, Karachi (competitive action)
2012	- First training on the JCS system (15 Euratom and 7 IAEA inspectors) in Ispra - In February, manufacture of the JCS number 500 (competitive action) - Important upgrading of the Candu reading heads, mainly improving the water tightness, decreasing weight.
2013	- for DG ENER, in Cernavoda, 1 reading system, 100 JCS seals, database software and infield support (AA) - Training on the JCS system (3 Euratom inspectors) in Ispra - Important upgrading of the shell of the software used by inspectors, in order to secure the access to signature of seals and forbid unintentional actions from inspectors

Impacts

The NuTraSeal action focussed on the technical support to the IAEA and Euratom. The main visible impact is related to the implementation of JRC seals in the spent fuel bays of various CANDU power plants.

The IAEA has used ARC seals manufactured by Atomic Energy of Canada Ltd. (**AECL Random Coil)** to seal underwater storage of spent nuclear fuel bundles in CANDU reactors located at the Cernavoda power generation facilities. After a nearly twenty-year service life, the ARC seal is no longer easily supportable. The Agency asked the JRC to develop a new CANDU sealing system. JRC spent a considerable effort in developing the design of the new sealing system and the first JCS seals were placed in the spent fuel pond in June 2006.

SILab supplied this unique system, patented by the European Commission, to implement the Safeguards Program. In 2008 the Ultrasonic Sealing became an IAEA category A approved equipment for worldwide use to seal spent fuel canisters. SILab is today the only provider in the world able to construct and commission this equipment.

Then the same sealing system was used in Pakistan, in the KANUPP nuclear plant, and later in the new reactor of Cernavoda II.

As one can see from the delivery of sealing systems (reading head, ultrasonic acquisition, signature database, toughbook computer, seals, handling tools, sealing accessories, …), both ENER & IAEA ordered and used a lot of sealing equipment. The CANDU sealing system developed by JRC is now in routine use in Europe in Romania and in the rest of the world in Canada & Pakistan.

The ultrasonic sealing system developed by SILab is now an essential tool used for safeguarding sensitive spent fuel coming out of Candu reactors and is by far much faster than the control of the physical presence of the nuclear material inside the storage casks.

Objective 2 Design, testing, internal vulnerability assessment and commissioning of ultrasonic bolt seals for dry application (JDS) on Castor flasks, including reading equipment and data transmission system.

Deliverables,

2007: 1 sealing system (reading head, acquisition system and software) for Vulnerability Assessment by a third party laboratory

50 JDS seals manufactured and supplied to the IAEA for Vulnerability Assessment by a third party laboratory

Impacts

JRC on request of IAEA and Euratom has developed a generic multi-purpose bolt seal for dry storage applications. This seal has the same performances as the underwater bolt seal, but specific features are added to prevent tampering. This was required because the seal is easily accessible in dry storage. The new sealing bolt is designed to fit Castor type containers (M24) but could be adapted to any container for dry storage.

The JDS sealing system was successfully tested for vulnerability in the Sandia National Laboratory.

Objective 3: Feasibility study to manage archiving and access to confidential and security printed documents based on unique identification of each page with passive transponders.

Deliverables,

2007: Proof of principle

2008: Feasibility report, preliminary demonstration system. With this preliminary study, we proposed three different solutions to manage security documents: system to manage existing archives, system to setup new archives, system for future archives. The first two solutions are based on the application of adhesive tags on printed documents; the last one is based on the innovative technology of special laminates. Also a preliminary demo to show the functionality of the system was set up. Representatives of DG ENER were invited at the demonstration and expressed their appreciation for the work done.

2009: Full demonstration system according to comments/requests done by DG ENER representatives on 2007 presentation.

Impacts

DG ENER asked the JRC to develop a system to manage classified documents. The present manual system is obsolete and shall be updated to improve the managing of documents avoiding errors in terms of unauthorized duplications or unauthorized handling. The request was directed to SILab because of the wide expertise demonstrated in nuclear and conventional applications using RFID technology. The promising capabilities of the system were demonstrated but at the end DG ENER decided to not implement it for its future management of classified documents.

Objective 4: Assistance to inspectorate

Deliverables

Training courses (IAEA/DG ENER - Infield & Ispra)

Several missions on site for assistance of inspectors and preventive (or corrective) maintenance of equipment delivered (Karachi, Darlington, La Hague & Cernavoda). Assistance is also often given remotely by phone or email, if the problem is linked to software issues, when related to mechanical issues it happened that we shipped equipment directly onsite.

Two training sessions for inspectors of DG ENER are scheduled each year, on request by DG ENER and/or IAEA SILab performed customised training sessions dedicated to particular arguments. SIlab is equipped with a training platform simulating the bridge used by operators and inspectors above the spent fuel pond and a pool equipped with mock ups of the different racks in use in the various CANDU facilities. Inspectors are train on the mechanical aspects of sealing using this equipment and as well are trained on the inspection software, the same as the one they will use in field.

Impacts

The impact of the training course is very high; a lot of inspectors followed the course in Ispra and on site. Appreciation is always very good.

Objective 5: Development of a low cost electronic seal

The request came through an EC SP1 call from IAEA in 2010, SILab was the unique laboratory to answer. The task consists in the development of an electronic seal with an active long cable (15m & optical fibre) able to resist high temperature constraints (-

40C +85C), with an extended battery life (5 years), a relatively low cost (200€) and advanced communication features.

Deliverables

- 2011: A first prototype was developed and proved the feasibility of the seal.

- 2012: Following test campaign and comments from the Agencies, another prototype developed and built in the JRC provided the functionalities required. The prototype has been delivered to the IAEA and DG ENER for evaluation. The in-house built prototype does not meet the environmental specifications, but only the functional.

- 2013: The JRC seal team tested its in-house prototype and wrote the specifications. A detailed study on the seal case and the connection of the fiber optic cable has been done, to provide a safe case and tamper proof connection. Development of a remote control interface using a cell phone. The prototype provided to DG ENER and the IAEA fulfilled the initial requirements, but IAEA set a new requirement for a metal case. This led to changes in the mechanical design that delayed the completion of the seal to 2014.

Impacts

The IAEA and DG ENER are very much interested in the development of such a seal, because of its potential to replace more expensive aging electronic seals already in use. Using more of such seals enables both agencies a reduction in missions and manpower, having the possibility to have real time alarm sent to headquarters. The seal, as developed at the end of 2013, fully answered the initial specifications, both IAEA and ENER received several seals and were able to test them and give already a very positive feedback.

Objective 6: Development of a copper brass seals verification station.

In 2012 a new arrangement has been setup with DG ENER for the realization of a copper brass seal verification station. DG ENER processes about 20,000 such metal seals per year and the verification consists in visually checking the identity of a copper brass seal, defined by a random stain pattern realized by the seal producer together with random scratches engraved when the seals are initialized. Formerly, seal initialization and verification were very heavy tasks as seal pictures were acquired with a camera one by one. The new verification station, developed by the JRC, has an automated image acquisition system allowing to easily processing seals in batches of 100 seals. To simplify the verification, a software automatically centers and rotates the newly acquired seal image in order to perfectly overlap with the reference image acquired during the production phase. The new system significantly speeds up seal production and helps particularly with the demanding task of seal verification. The new tool has been in routine use since mid-2013.

Deliverables

- 2012: Collection of user needs and development of the first verification station.
- 2013: One system has been delivered to DG ENER on May 2013. DG ENER technicians have been trained on the system use and in the first day of use the new station has been already used for the initialization of a batch of 1000 seals. The second system to be delivered according to the contract is being finalized taking into account the improvements suggested by the end users during the first months of use.

Impacts

The verification system has been realized in the framework of an administrative arrangement (contract n. 32594 “Upgrade of optical copper brass seal verification system with automated image acquisition”). Since May 2013, all the operations related to the management of copper brass seals have been successfully carried out using the system developed by JRC, greatly enhancing the productivity of these tedious but extremely important verification tasks. The average time of verification was reduced by a factor of 5, decreasing greatly the work load and manpower needed for such tedious tasks.

Objective 7: Development of an Ultrasonic Optical Seal Bolt (UOSB)

Beginning of 2012, IAEA asked JRC to work on a new concept combining an ultrasonic bolt seal and an active seal with optical fiber. There is a strong need for the development of compact sealing bolt, to be applied to nuclear containers in dry conditions. The need is for a seal easy to be controlled after first installation and with the possibility of being checked remotely even from headquarters. The seal has to be easy to be installed and verified to avoid high irradiation levels to the operators. It should be also derived from a seal already approved to ease the vulnerability assessment. With an optical fiber passing through the ultrasonic bolt seal, It is possible to check with the ultrasonic reading head at the first installation, while the continuity of the fiber optic, monitored by a dedicated seal, check the fiber loop continuously. Such seals could be extensively used on dry storage casks, as for example in Lithuania on Castor and Constor casks.

Deliverables

- 2012: First design, patent written, development of first prototypes and in-house tests.
- 2013: Development of first operational prototypes and inserts, followed by a first field mission in July 2013 and a positive vulnerability assessment made by a Russian VA team. Development of a prototype of portable reading system, lightweight and battery operated. Development of the electronics boards, firmware and software.

Impacts

More than 100 casks are already stored in the old storage area in Ignalina, four UOSB will be needed on each cask and a lot more casks will be stored in the new huge storage area just built. The interest of both IAEA and DG ENER is enormous because right now the inspector has to climb on the top of those huge and high casks, which is a tedious and risky task (vertical ladder, radiation, weather …). Using UOSB system, it will enable the inspector to verify once from the top of the casks but then leave the UOSB hidden under a cover and checking for several years the electronic (EOSS) or passive (Cobra) seals from the ground level. The development of this new system from the idea to the operational deployment has been extremely fast and efficient.

Note: The UOSB was approved as category A, ready for operational use, in September 2014.

3.3. Major Highlight(s)

2007: Conception and production of the first ultrasonic bolt seals for CANDU underwater spent fuel storage and associated field test in Cernavoda (Romania).

2008: The JRC Candu Sealing System approved as category A by the IAEA.

2009: First components of the new JRC Kanupp Sealing System delivered to Karachi (Pakistan).

2010: Installation of JRC Candu Sealing Systems in Darlington (Canada).

2011: First group training in Ispra for inspectors. First installation of JRC Candu Seals in Cernavoda II.

2012: First prototype of the low cost electronic seal. Manufacture of the 500th JCS seal. New reading system tested in La Hague (France).

2013: First verification station for copper brass delivered to Luxemburg.

4. Further Information

During the period JRC received several appreciation letters from IAEA:

- 26/01/2009: Letter from N. Khlebnikov, director of the division of technical support, department of Safeguards to the director of IPSC: “I have the pleasure of writing to you to express our appreciation of the work (…)” related mainly to Ultrasonic Sealing Bolt, classified as category A.

15/04/2011: Letter from S. Zykov, director of the division of technical support, department of Safeguards to the director of ITU, copy director of JRC: “I wish to express sincere appreciation (…)”related mainly to JCSS (JRC Candu Sealing System) and the development of the low cost active electronic seal.

23/01/2014: Letter from V. Zyl de Villiers, acting deputy director general, department of Safeguards to the director of JRC: “I have the honour to express IAEA sincere appreciation for the invaluable support provided by the JRC (…)” related to JCSS, the new active low cost seal and the novel dual seal UOSB (Ultrasonic Optical Sealing Bolt).

4.1. Integration and Networking

JRC/IPSC/TRVA/SILab is member of the Esarda (European Safeguards Research and Development Association), network where all the European stakeholders (but also non-European) in nuclear safeguard regularly meet.
The laboratory is also a permanent member of the Working Group on Containment and Surveillance.

4.2 List of Competitive Activities

IAEA			
Reference	Date	Items	Quantity
2008-1272	16/06/08	JCS reading system	2
2008-1684	23/07/08	JRC Candu seals	100
2008-1682	10/09/08	Handling tools Cernavoda II	1
2009-1452	03/07/09	Reading system	2
		Handling tools	1
		JRC Kanupp seals	30
		Tie rods	30
2010-0846	05/06/10	1 Reading system + 50 JCS	1
		1 Reading system + 100 JCS	1
2011-10505		JRC Candu seals	100
		Shipping & case	1
2011-05392	22/11/11	JRC Candu seals	50
		JRC Kanupp seals	30
2011-03759	22/09/11	Tie rods	30
2013-06583	13/11/13	Tie rods	30
		JRC Kanupp seals	30
2013-06545	25/11/13	Tie rods	30
		JRC Kanupp seals	30
2013-06978	09/12/13	UOSB	60
		Inserts	60
		Total	

DG ENER			
Reference	Date	Items	Quantity
31837-2010	16/08/10	1 JCS reading system	1
		75 JCS	
		Training kit	
		In field support	
31989-2010		1 JCS reading system	1
		1 set of end fittings	
		USB key	
		In field support	
32884 - 2013		1 JCS reading system	1
		100 JCS seals	
36 months		Database software	
		In field support	
32755-2012		2 JHS reading systems	1
		50 JCS seals	
		Adhoc US software	
24 months		Training	
		In field support	
		Total	

5. Other Information

5.2. Patents and Licenses

	NUTRASEAL		
		Title	Comments
1	2561	PROCEDE DE FABRICATION DE NOYAUX D'IDENTITE POUR DES SCEAUX A ULTRASONS	Basic concept. Innovative.
2	2622	SCELLE MULTI-USAGE ELECTRONIQUE A TRANSPONDEUR PASSIF	Non-nuclear. Innovative. Wrongly denominated 2643 in SILab patents list
3	2655	METHODE D'IDENTIFICATION D'UN OBJET	?
4	2676	Scellé multi-usage à serrure	?
5	2692	ORGANE DE FIXATION A INTEGRITE CONTROLABLE	Non-nuclear. Innovative.
6	2694	Sealing clamp based on multi-transponders technology.	Non-nuclear. Innovative.
7	2725	ELECTRIC FIELDS SENSOR.	?
8	2737	Sealing device and method for sealing.	Compressed air. Not very innovatinve.s Abandon?
9	2738	Sealing bolt.	Dry Storage. Innovative.
10	2747	Low vulnerability bolt seal.	Dry Storage. Innovative.
11	2818	Sealing device.	RFID seal for containers. Licensed
12	2914	Ultrasonic sealing and identification system for nuclear dry storage applications looped by fiber optics	Patent application?
13	2933	Tamper proof stud	Patent proposal
	Abandonned		
	2374	Ultrasonic Sealing Bolts and identification bolts	
	2627	Système d'identification d'objets	
	2742	Container surveillance system	
	2749	Electrostatic field imager	
	2880	Patent for a seal based on GPRS remote monitoring and verification	
	2881	Indicative sealing clamp based on RFID UHF pasive transponder technology	

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action n° *53102 METRO*
Providing metrological tools to support nuclear safeguards activities
Action Leader: *Yetunde Aregbe – Standards for Nuclear Safety, Security and Safeguards (SN3S)*

Authorising Officer: *Wim Mondelaers – SN3S Unit*
Leading Institute: *Institute for Reference Materials and Measurements – JRC-IRMM*

0. Policy Area

Policy theme 5 – The EURATOM programme

Agenda 5.3 – Nuclear security

Sub-agenda N° & Title: 5.3.1 Nuclear Safeguards, Additional Protocol and Combating Illicit Trafficking

1. Rationale of the Action:

Nuclear power is accounting at present for one third of current electricity generation in the EU. Implicit is the high priority given to nuclear safety, security and safeguards ("3S) in the EU and worldwide. The EU, with its large multinational nuclear industry, has a particular interest in ensuring that the peaceful uses of nuclear energy take place with the highest standards of nuclear safety, security and non-proliferation (*citation: former President of the European Council, Herman van Rompuy, on behalf of the EU at the Nuclear Security Summit 2012*). Effective European and international nuclear safeguards authorities have to meet the challenges of satisfying increasing energy demands, tackling climate change, re-invigorate nuclear arms control and non-proliferation contributing to peace and security. This requires a strong verification and detection system in place to safeguard nuclear materials and activities in line with the Euratom Treaty, the global Nuclear Non-Proliferation Treaty (NPT) and the additional protocol (INFCIRC/540). Measurements and measurement standards provide the basis for any verification and detection system. Particularly advances in environmental sample analysis and nuclear forensics are of main interest towards a safeguards system meeting tomorrow's challenges and demand new kinds of reference materials (Nuclear Security Summit 2014). The JRC-IRMM is an internationally renowned and accredited provider of specific measurement quality tools. In Article 8 and Annex V of the Euratom Treaty the need for isotopic standards is stated recognising the essential part that reference materials play in measurements of nuclear materials. The provision of specific reference materials, reference measurement services and interlaboratory comparisons to safeguards authorities, industry and measurement laboratories in the field for accurate measurements of nuclear (fissile) material, of environmental samples and of seized materials, are at the heart of nuclear security and safeguards in Europe and the world.

Nuclear data measurements for studies in the context of reactor safety, waste transmutation, safeguards and security require well characterised targets. Without these high quality targets with uncertainties below the target nuclear data uncertainties, no measurement effort may reach the desired goal. The JRC-IRMM capabilities and competences in developing, characterising and providing nuclear targets are unique and are a main contributor to the excellence of the JRC in this core field for the EURATOM programme.

2. History and development of the Action:

Activities in this action are part of the JRC nuclear sub-core areas of nuclear security and nuclear safety and the cross-cutting area Reference Materials and Measurements. Action 53102 has during FP7 expanded its support from providing quality control tools and knowledge transfer for nuclear safeguards and safety to developing new reference materials and conformity assessment tools in the fields of nuclear security and forensics. Action 53102 has strengthened the inter-unit, inter-institutional and inter-DGs cooperation building on shared knowledge and know-how.

This resulted in more effective policy and scientific support to customer DGs and external parties in compliance with the respective legal framework (see paragraph on description of the action).

A brief timeline of action 53102 in FP7 is given below:

- In March 2007 Roger Wellum, the former action leader, retired and Yetunde Aregbe became new action leader of 53102 METRO
- On request of the JRC Deputy Director General in 2008 (A. Pauli), a business plan was established and the action's resources were consolidated to ensure development and production of reference materials and targets and to guarantee transfer of knowledge to the next generation of technicians and researchers in the nuclear field
- After the period of decommissioning in FP6 the needs for and requests to JRC-IRMM on well characterised targets for nuclear data measurements and also for reference materials for reactor dosimetry increased. The first is mainly to support studies on waste transmutation and safety of reactor system, the latter was an increasing need from nuclear industry on reference materials for reactor safety. To respond to these increasing needs action 53102 made a major and successful effort in 2007 and 2008 to partly revive target preparation activities at the JRC-IRMM
- From 2008 onwards action 53102 joined efforts with the respective JRC-ITU action (53103) into supporting the JRC nuclear forensics and security activities by developing respective quality control tools, also in cooperation with JRC-ITU
- On 1 July 2009 the action 53102 was transferred from the Isotope Measurements Unit to the Reference Materials Unit at JRC-IRMM, carrying out all the work under the respective accreditation scope (see paragraph on description of the action)
- From 2009 on action 53102 increased its active education training and knowledge transfer activities via contribution to academic/training courses and organisation of relevant workshops/training/exchange with various communities from students to professionals
- On 1 January 2013 the action 53102 was transferred from the Reference Materials Unit to the Unit for Standards for Nuclear Safety, Security and Safeguards (SN3S) at JRC-IRMM

3. Description of the Action

Action 53102 supports the implementation and monitoring of EU policies in the fields of nuclear safeguards, security and safety by providing metrological tools, including reference materials, reference measurements and interlaboratory comparisons for building up confidence in the comparability and reliability of specific measurement results on nuclear material and environmental samples. Action 53102 puts efforts in research and development of new quality and conformity assessment tools in anticipation of future needs and challenges of its customers. Furthermore .The activities carried out at JRC-IRMM under action 53102 fulfil the JRC's obligation under Article 8 and Annex V of the Euratom Treaty and are performed under multi-annual commitments such as the AAs with DG ENER-E and DGDEVCO, the EURATOM - US-DOE CA, the EC support programme to the IAEA, framework contracts and in the

frame of the JRC support to standardisation. Furthermore action 53102 provides scientific/technical advice, and organises and supports training/education activities to alleviate the risk of the loss of nuclear knowledge for the European Union. The five core competences of action 53102 are the following:

1) Provision of certified nuclear reference materials (CRMs); accredited under ISO Guide 34

2) Provision of state-of-the-art reference measurements on nuclear material and environmental samples; accredited under ISO 17025

3) Provision/coordination of Inter-laboratory comparisons on samples analysed in fissile material control and for environmental traces characteristic for the nuclear fuel cycle; accredited under ISO17043

4) Provider of well characterised targets for measurements in nuclear physics for nuclear safety and nuclear safeguards applications

5) Scientific expert advice and training

The core expertise of action 53102 as listed above is carried out under EURATOM and JRC formal commitments, obligations with DGs and international organisations.
The main legal framework of action 53102 in FP7 is listed below:

- Provision of certified reference materials and measurement certificates to DG ENER-E under respective Administrative Arrangements as part of the MEMORANDUM OF UNDERSTANDING (MOU) № JRC BXL MOU 32924 - 2012 BETWEEN THE DIRECTORATE-GENERAL FOR ENERGY (DG ENER) AND THE JOINT RESEARCH CENTRE (JRC) ON THE PROVISION OF SCIENTIFIC AND TECHNICAL SUPPORT RELEVANT TO EUROPEAN UNION POLICIES IN THE AREA OF ENERGY (*former: Memorandum of Understanding NO.JRC.BXL.30978 between the Directorate General for Energy and Transport and the Joint Research Centre on the provision of scientific and technical support to DGTREN on nuclear safeguards and fissile material control)*

- 5 years (2013-2017) FRAMEWORK SALES CONTRACT NUMBER – 30777: The European Community, represented by the Commission of the European Communities and Japan Nuclear Fuel Limited (*former: Framework sales contract agreement 2008/2 TO No. 30902 between IRMM and JNFL signed on December 19, 2007 for the supply of large sized dried spikes (LSD) to Japan Nuclear Fuel Limited from 2008-2012*).

- Five support tasks to the IAEA under the *IAEA Cooperative agreement from 1976*; with a Statement on reinforcing cooperation between the IAEA and the European Commission in 2008

- Amendment to the *Memorandum of Understanding NO.JRC.BXL.180092* between the Directorates General of External Relations, Development, Europeaid, Trade, Enlargement, Echo and the Joint Research Centre on the provision of scientific and technical support relevant to the external relation

policies of the RELEX family. Annex 1: Nuclear Safeguards and Non-proliferation

- Provision of scientific/technical advice under respective Administrative Arrangements as part of IFS 2011276421 between DGDEVCO and the JRC on the establishment and implementation of the "Expert Support Facility" for the "Instrument for Stability". Communication on strengthening chemical, biological, radiological and nuclear (CBRN) security in the EU, including an EU CBRN Action Plan (COM(2009)273).

- Action sheet 43 and 36 under Agreement between the United States Department of Energy and the European Atomic Energy Community represented by the European Commission in the field of Nuclear Material Safeguards and Security Research and Development, Nov 2010.

- Project sheet Priority area 1 (Reference materials): *C 11801 COLLABORATION AGREEMENT* between THE JOINT RESEARCH CENTRE ON BEHALF OF THE EUROPEAN COMMUNITIES and THE COMMISSARIAT À L'ÉNERGIE ATOMIQUE

- JRC - JAEA collaboration agreement in the field of Nuclear Safeguards, Security and Non Proliferation

- European Council conclusions on standardisation and innovation (Brussels, 25/09/2008) of the Commission flagship "An industrial policy for the globalization era" (COM(2010)614).

- JRC-IRMM collaborative measurement activities in EU and international context, i.e. OECD-NEA and IAEA, EURATOM collaborations with US-DOE

- Council conclusions on the need for skills in the nuclear field (15406/08; 16577/08 (Presse 354).

3.1. Clients and Stakeholders

Customer/users (outside the European Commission):

• International Atomic Energy Agency (IAEA)
• Korea Atomic Energy Research Institute (KAERI), South Korea
• British Nuclear Fuels (BNFL), UK
• Sellafield-site, UK
• Japan Nuclear Fuels Limited (JNFL), Japan
• Nuclear Material Control Centre (NMCC), Japan
• Japan Atomic Energy Agency (JAEA), Japan
• Commission d'ETAblissement des Méthodes d'Analyse du CEA (CETAMA), France
• Commissariat à l'Energie Atomique (CEA), France
• United States Department of Energy - New Brunswick Laboratory (NBL), USA
• United States Department of Energy - Lawrence Livermore National Laboratory (LLNL), USA
• URENCO, The Netherlands
• CERCA/AREVA, France
• Paul Scherrer Institute, Switzerland

• AECL Chalk River, Canada
• Beijing Yuan Feng Science and Technology Development Corp., China
• Massachusetts Institute of Technology, USA

Customer (inside the European Commission):
• ENER (former DG Energy and Transport)
• European External Action Service - EEAS (former DG External Relations)
• DEVCO (former DGAIDCO)
• HOME
• GROWTH (former Enterprise and Industry

3.2. Major Objectives, deliverables and impacts

Objective 1: Provision of certified nuclear reference material (CRMs); accredited under ISO Guide 34

Deliverables, Five new uranium, three new plutonium and seven mixed uranium/plutonium reference materials were developed and certified during FP7. From 2007-2013 all in all 7500 units of certified nuclear isotopic reference materials for nuclear material and environmental sample analysis were provided to EURATOM and international safeguards laboratories, industry and the measurement community.

Impacts: The EU is committed to ensure that the peaceful uses of nuclear energy take place with the highest standards of nuclear safety, security and safeguards (“3S”). Recent international events have highlighted the importance of worldwide trust in the mechanisms ensuring safeguarding nuclear material. Irrespective the future evolution of nuclear energy verification and detection of nuclear materials will remain crucial. By providing measurement quality control tools, such as certified reference materials, the JRC is directly contributing to the effectiveness of nuclear safeguards and security systems, supporting the authorities in meeting the challenge to achieve their required high level of detection probability.

Objective 2: Provision of state-of-the-art reference measurements on nuclear material and environmental samples; accredited under ISO 17025

Deliverables, During FP7 the JRC-IRMM developed the modifier total evaporation technique for thermal ionisation mass spectrometry (MTE-TIMS) and established the measurement capability for low-level nuclear measurements of environmental samples, in particular also for measurements of uranium particles. Reference measurement certificates for uranium hexafluoride on samples received from EURATOM safeguards and on other materials were issued. Furthermore reference measurements were carried out as part of successful participation in a number of external interlaboratory comparisons.

Impacts: In the EU nuclear safeguards has the rank of European law. To ensure the measurement capability is kept at the forefront for isotopic measurements of U and Pu has been done in action 53102 by developing new techniques and providing state of the art measurement service. This is the basis for reliable measurements and confidence in measurement results in nuclear material analysis. Particularly by providing reliable measurement results on samples that have been taken by Euratom safeguards inspectors the JRC is contributing directly to the

verification that nuclear activities are peaceful only and to deter the proliferation of nuclear weapons.

Objective 3: Provision/coordination of Inter-laboratory comparisons (ILCs) on samples analysed in fissile material control and for environmental traces characteristic for the nuclear fuel cycle; accredited under ISO17043

Deliverables, Three NUSIMEP and one REIMEP Interlaboratory comparisons were coordinated and completed, another REIMEP ILC was initiated. All these ILCs were organised in support to EURATOM safeguards, the IAEA Network of Analytical Laboratories and the International Nuclear Forensics International Technical Working Group, in close collaboration between JRC-IRMM and JRC-ITU.

Impacts: The control of civil nuclear material is mandatory within the EU. Safeguards conclusions are based to a large extent on comparison of measurement results between operator and safeguards laboratories. These measurements need to be subjected to a rigorous quality management system meeting internationally agreed target values (ITV2010) for nuclear material and quality goals for environmental sample analysis. By means of interlaboratory comparisons the measurement capability of both the Euratom and IAEA safeguards and the nuclear operator's analytical services can be assessed against the independent reference values as well as against internationally agreed quality goals, in compliance with ISO 13528:2005. This provides confidence in measurement results that, in the worst case, have to stand in court.

Objective 4: Provider of well characterised targets for measurements in nuclear physics for nuclear safety and nuclear safeguards applications

Deliverables, During FP7 JRC-IRMM successfully revived some of the target preparation activities and prepared more than 150 targets in support to nuclear physics experiments carried out at the two accelerator sites at JRC-IRMM and in the frame of international collaborations

Impacts: About 32% of the electricity produced in the EU comes from nuclear energy, and regardless of the energy policy choices made by every State, accurate nuclear data and nuclear material measurements are the fundament of any political decision on nuclear energy demands, nuclear safety, waste minimization and in achieving the required high level of detection probability in nuclear safeguards. With its target preparation, the JRC-IRMM is in pole position to support these fundaments

Objective 5: Scientific expert advice and training

Deliverables: From 2009-2014 technical/scientific advice was provided to DGDEVCO and EEAS to identify the appropriate activities and the most efficient way for using the EU contribution of € 10 million for the project *Enhancing the Capabilities of the International Atomic Energy Agency Safeguards Analytical Services* (IAEA-ECAS) from the Instrument for Stability. During FP7 staff from action 53102 contributed and/or organised and hosted JRC, ESARDA, and BNEN training/education activities in the field of nuclear safeguards and non-proliferation, destructive analysis, use of reference materials, and metrology. Furthermore training on mass spectrometry was provided to the IAEA Safeguards Analytical Service under the respective European Support Programme task and training on target preparation under cooperation agreements. Furthermore trainings on metrology in Chemistry and on the production and certification of nuclear reference materials have been provided

to scientists from the D.I. Mendeleyev Institute for Metrology (VNIIM-Russia) in the frame of TACIS

Impacts: The EU CHEMICAL, BIOLOGICAL, RADIOLOGICAL AND NUCLEAR SECURITY Action Plan aims at reducing the threat and possible consequences of CBRN incidents of accidental, natural or intentional origin, including acts of terrorism. A paragraph on the close and successful cooperation of the European Commission (DG DEVCO and DG JRC) and EEAS in the frame of ECAS is included in the joint staff working documents on EU efforts to strengthen nuclear security published at the occasion of the Seoul Nuclear Security Summit (2012) and the Nuclear Security Summit in The Hague (2014). In general the activities done by action 53102 on knowledge, transfer in the field of safeguards, security and safety are essential and directly supporting the Council conclusions on the need for skills in the nuclear field (15406/08; 16577/08 (Presse 354).

3.3. Major Highlight(s)

2007: MoU with DG TREN (now: ENER) for the continuous supply of uranium/plutonium mixed spikes to be used for verification measurements in the EURATOM on-site laboratories in Sellafield (UK) and La Hague (F) under administrative arrangements; 5-year framework contract with JNFL on supply of uranium/plutonium mixed spikes: https://ec.europa.eu/jrc/en/news/nuclear-material-only-peaceful-purposes-jrc-releases-reference-material-irmm-1027p?search

2008: On the basis of the successful exploratory research in 2007 the interlaboratory comparison NUSIMEP-6 focusing on measurements of uranium isotope amount ratios in uranium particles was organised, in response to needs of the IAEA network of analytical laboratories for environmental sampling (NWAL). It was the first NUSIMEP of its kind. https://ec.europa.eu/jrc/en/interlaboratory-comparisons/NUSIMEP; https://ec.europa.eu/jrc/en/interlaboratory-comparisons/REIMEP

2009: As part of the successful series of large-sized dried (LSD) spikes for uranium and plutonium produced at IRMM, a new batch, labelled IRMM-1027m has been completed. These spikes are applied to measure the uranium and plutonium content of dissolved fuel solutions using isotope dilution mass-spectrometry. The spikes are prepared in large batches under rigorous conditions. They are dispensed by means of an automated robot system allowing in an optimised manner to meet the customer requests for large size dried spikes production in large batches. The dried uranyl and plutonium nitrates are embedded in a cellulose substance.to retain the spike at the bottom of the vial during transport to where it will be used. The spikes are a fundamental part of material accountancy and verification control of dissolved nuclear fuel. https://ec.europa.eu/jrc/en/reference-materials

2010: IRMM-046b is a mixed spike Isotopic Reference Material of highly enriched ^{233}U and ^{242}Pu that dates from 1995. It is applied for Isotope Dilution Mass Spectrometry (IDMS) in nuclear fuel cycle measurements. IRMM-046b was recertified for isotope amount content and isotopic composition in the scope of the inter-calibration campaign inter-linking selected IRMM plutonium spikes on a metrological basis applying state-of-the art measurement procedures. *Journal of Radioanalytical and Nuclear Chemistry November 2010, Volume 286, Issue 2, pp 449-454*

2011: Release of a new uranium CRM. The uranium isotopic reference material IRMM-3100a is a equimolar mixture with isotope amount ratios $n(^{233}U)/n(^{235}U)/n(^{236}U)/n(^{238}U)$ close to 1/1/1/1 prepared by dilution of a gravimetrically

mixed primary solution made from purified amounts of highly enriched uranium oxides. This QUAD Isotopic Reference Material is very suitable for verification of inter-calibration of multi-collector mass-spectrometers, especially those equipped with multiple ion counting systems, widely applied for measurements of uranium in nuclear safeguards and earth sciences. *International Journal of Mass Spectrometry 299 (2011) 120–124*

2012: The European Union has been supporting the project Enhancing the Capabilities of the International Atomic Energy Agency Safeguards Analytical Services (IAEA-ECAS) with €10M from the Instrument for Stability (IfS 2010/273-571and IfS 2012/306-680) for the construction of the new nuclear material Laboratory. On request of EEAS and DGDEVCO the Action fiche, with major input from JRC-IRMM was approved by the quality control group and the committee for the instrument for Stability and provided the basis for the technical "ANNEX I – Description of the Action of the contract IfS 2012/306-680 Joint EC-IAEA project" " signed in December 2012. Furthermore, the JRC's support to ECAS has been explicitly acknowledged by the EEAS Directorate Conflict prevention and Security Policy. It is a successful example of inter-service cooperation supporting the European Commission in its work in the area of conflict prevention, crisis management and peace building: http://www.iaea.org/newscenter/news/iaea-nuclear-material-laboratory-inaugurated

2013: High quality measurements of nuclear data and materials are being asked for in the context of nuclear safety, minimization of high level nuclear waste and safeguards and security. High quality nuclear targets produced by the best available techniques and characterised by state-of-the-art methods are indispensable. The quality of the targets sets the lower limit of uncertainty that may be achieved. Without these high quality targets with uncertainties below the target nuclear data uncertainties, no measurement effort may reach the desired goal. IRMM published recently four articles on the preparation of new sophisticated targets: https://ec.europa.eu/jrc/en/news/advances-target-preparation-techniques-jrc-accurate-nuclear-physics-measurements?search

From 2007-2013 all in all 7500 units of certified nuclear isotopic reference materials for nuclear material and environmental sample analysis were provided to EURATOM and international safeguards laboratories, industry and the measurement community.

4. Further Information

4.1. Integration and Networking

Action 53102 has a long and successful record of within institute and between institutes cooperation and is a renowned member in networks and platforms.

a) collaboration within the JRC

Within the JRC-IRMM action 53102 has been in FP7 closely cooperating with the other JRC-IRMM actions (11103, 51402, 51401, 51603, 33004) as far as target preparation and projects under the JRC-IRMM accreditation scope of 17025, 17043 and ISO Guide 34 were concerned. Action 53102 and JRC-ITU actions 53103, 53108 have been closely collaborating during FP7 on reference material development and provision, certified test sample preparation, organisation of ILCs and in the field of education and training.

b) collaboration with DG customers

Action 53102 has been providing policy and scientific support in close and regular exchange with its main customer DGs ENER, DEVCO and the EEAS (former TREN, AIDCO, RELEX) under the respective legal commitments (MoUs and AAs) but also via the platforms of ESARDA, INMM and the IAEA EC SP. Particularly the project on the JRC support to ECAS as part of the project area 2 under priority "support for the objectives of the EU CBRN risk mitigation strategy" of the long-term component of the Instrument for Stability was a very successful example of this inter-service cooperation

a) External collaborations

Action 53102 prioritised the objective and deliverables of each annual work programme in FP7 with its customer DGs and via exchange with the main customers at international level. The following platforms/networks were used on a regular basis in this prioritisation process:

- Regular meetings with DGENER-E on the supply of CRMs and reference measurements under the respective AAs
- Participation with EEAS (former RELEX) in respective IAEA workshops for the EU contribution to ECAS from the IfS
- European Commission Support Programme to the IAEA and technical meetings with the IAEA Network of Analytical laboratories (IAEA-NWAL); JRC-IRMM is part of the IAEA-NWAL for reference materials
- Action sheets under the CA between EURATOM and the US-DOE
- European Safeguards Research and Development Association (ESARDA): CRM priorities are every year reviewed with the IAEA, DGENER, CEA/CETAMA, US-DOE NBL and the nuclear industry in the ESARDA Working Group on Standards and Techniques for Destructive Analysis. This working group was (co)-chaired by action 53102 for 5 years
- Member of the CEA/CETAMA WGs on U, Pu and isotopic analysis, with CEA/DEN, CEA/DAM and the French Nuclear industry (AREVA)
- JNFL-Japan and TNT-Tokyo on the needs of U, Pu CRMs under the respective framework contract
- MoU with URENCO Nederland BV on the Optimisation of uranium reference particle production and characterisation
- Observer in standardisation committees (ASTM, ANSI)
- Member of the INTDS – International Nuclear Target Development Society
- IRMM CRMs user-producer meetings with participants from DGENER, JRC-ITU, IAEA and industry

4.2 List of Competitive Activities

Provision of certified reference materials and measurement certificates to DG ENER-E under respective Administrative Arrangements as part of the MoU DGENER JRC BXL MOU 32924 -2012 – JRC (former NO.JRC.BXL.30978)
Framework sales contracts no. 30777 and 30902 with Japan Nuclear Fuel Limited
Distribution of reference materials (approx. € 2.5 million 2007-2013).

4.3. Mobility and training of researchers

2007-2013

- 2 PhD theses were successfully completed, one from (former) new Member State
- 1 PhD student (thesis currently in finalisation)
- 1 traineeship of a student
- 1 stagiaire
- 7 post-doctoral researchers, 3 from (former) new Member States

EUROPEAN COMMISSION
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JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2011

Action *53103 FACIL Forensic Analysis and Combating Illicit Trafficking*
Action Leader: *Klaus Mayer, E07*

Authorising Officer: Klaus Luetzenkirchen, E07

Leading Institute: Institute for Transuranium Elements (ITU)

0. Policy Area

Policy theme 5. The EURATOM programme
Agenda 5.3 Nuclear security
Sub-Agenda 5.3.1 Nuclear Safeguards, Additional Protocol and Combating Illicit Trafficking

1. Rationale of the Action:

The EU Common Foreign Security Policy, the European Security Strategy (2003), the EU Strategy Against Proliferation of Weapons of Mass Destruction (WMD), the EU Counter Terrorism Strategy (2005) and the New Lines for Action in Combating the Proliferation of WMD and their Delivery Systems endorsed in 2008, all together reinforce the EU commitment to nuclear security. More recently, the EU has underlined the high priority Member States and the Commission attribute to nuclear security at the Nuclear Security Summits 2010, 2012 and 2014. The instruments established for addressing these issues include the CBRN Action Plan, the Instrument for Stability and the CRBN Centres of Excellence. In the concrete implementation, the concerns arising from illicit trafficking of nuclear and other radioactive material, the proliferation risks associated with it and the threat of nuclear terrorism call for a set of measures comprising prevention, detection and response. Nuclear security is getting increased attention at all levels, ranging from international initiatives (Global Initiative on Combating Nuclear Terrorism, Proliferation Security Initiative, UNSC 1540, and others) to multilateral cooperation and to technical developments. JRC-ITU has a long standing experience in the area of nuclear security. Its involvement can be presented along three major lines:

- Research and development
- Support to Member States and International Organizations
- Capacity building activities

2. History and development of the Action:

Nuclear Forensic Science became an essential activity in support to international organizations, to Member States authorities and to regulatory bodies. This contributed to steadily and significantly raise JRC's profile in the Nuclear Security area. The action was created in 2007 by splitting an earlier action, separating out nuclear security related activities (then included in FACIL) from nuclear safeguards focused activities (then covered by NTAS). This also reflects the increased attention nuclear security activities have gained on the political level, and increases the visibility of ITU's activities in this area.

3. Description of the Action

JRC-ITU has been carrying our activities for developing, implementing and improving technical capabilities to respond to nuclear security events such as illicit trafficking. This includes the development of methods and the identification of characteristic parameters for nuclear forensics, including classical forensics on contaminated evidence. Appropriate measurement methods and data interpretation techniques are developed. Moreover, the collaboration with national authorities (such as law enforcement, regulatory, radiation protection) and international organizations (such as the IAEA,

GICNT or Europol) is given a high priority. In particular the nuclear forensic analysis of nuclear material found out of regulatory control is provided as a service to Member State authorities. This scientific/technical work is encompassed by steadily training activities. The implementation of the European Nuclear Security Training Centre (EUSECTRA) marked a milestone in the training capabilities of JRC-ITU.

It should furthermore be noted that responding to nuclear security incidents and the implementation of nuclear security measures involves different authorities and requires different skills. The interaction between regulatory bodies, prosecution, law enforcement and scientific institutions calls for a coordinated plan of action and for the development of a response methodology which also needs to be exercised. These aspects also need to be addressed by the action.

3.1. Clients and Stakeholders

Major clients for this action are Member State authorities, the International Atomic Energy Agency (IAEA), DG JLS, DG TREN, Europol, Interpol and DG RELEX (in the framework of the Instrument for Stability)

3.2. Major Objectives, deliverables and impacts

The action aims at further improving the knowledge base in nuclear forensic science (Objective 1), at supporting investigating authorities in incidents of illicit trafficking (Objective 2) and at capacity building within and outside the EU (Objective 3).

Objective 1: Nuclear forensics development

Nuclear forensics makes use of parameters inherent to the material that provides information on the history of the nuclear material. In consequence, investigations have to be carried out to identify characteristic parameters in nuclear material (e.g. samples of uranium ore concentrate from different geographic locations) comprising parameters like metallic impurities, isotopic composition of major and minor components, microstructure and crystal structure. Specific analytical methods need to be developed or adapted. The interpretation of the measurement results makes use of subject matter expertise as well as of statistical techniques and interpretation techniques.

Deliverables: A set of some 80 samples of yellow cake (originating from different uranium mines across the world) could be obtained. Different material properties (such as isotopic composition, chemical impurities etc.) were investigated in order to identify characteristic parameters. New and improved analytical methods were developed for measuring these parameters. The results were presented at international conferences and published in peer-reviewed journals (see section 5.3 publications).

Impacts: The results of this research were of direct use for the investigative case work in support of member states. Peer reviewed papers and conference contributions underlined ITU's prominent role as nuclear forensic laboratory.

Objective 2: Nuclear Forensic Support to Member States and international organizations

In support to member states and other requesting countries the analysis of nuclear

material is provided if and when required (e.g. seizure of nuclear material).

Deliverables: In the reporting period, requests for nuclear forensic support were received from Belgium (2007), the Netherlands (multiple cases: 2007, 2009, 4 x 2010, 2 x 2011, 2 x 2013, 2014), Finland (2010), Moldova (2011), Germany (three cases: 2 x 2007, 2014) and Slovakia (2008). The results of the nuclear forensic investigations were provided to member states authorities by means of (limited distribution) reports. Joint exercises were held with some member states, in order to practice the transfer of samples and to enable the participation of national experts in the nuclear forensic analysis carried out in ITU's laboratories.

Support to the IAEA was provided through consultancies and involvement in the preparation of the nuclear security conference 2013. Several actions from the EU-CBRN Action Plan were implemented through Administrative Arrangements with DG HOME (formerly DG JLS). This included a project on measures to improve the usability of the IAEA's Incident and Trafficking Database. Events of the Global Initiative to Combat Nuclear Terrorism were attended and the inaugural meeting of the GICNT Nuclear Forensics Working Group was hosted at Karlsruhe (2011) and a GICNT focus group meeting was held at JRC-ITU premises (2013).

Impacts: The results of the nuclear forensic investigations carried out by the FACIL action were highly useful to the competent national or international authorities in non- proliferation, in prosecution and in counteracting nuclear threats by establishing the origin of the findings.

Objective 3: Capacity building and training

Training of staff is of key importance for the implementation of nuclear security measures. ITU shares its experience and expertise in the nuclear security area with member states and with international organizations. To this end different training programs need to be developed or improved and the respective training modules have to be elaborated or updated. Training sessions and workshops are be organized (some of the jointly with other organizations) to disseminate the knowledge. The training activities are complementary and/or carried in collaboration with the activities organized within the nuclear security actions at IPSC (ITU Ispra).

Deliverables: Training courses in the area of response to nuclear security incidents (response and nuclear forensics) were organized, the appropriate didactic material was updated. A dedicated training course on nuclear security related issues using the web-based calculation and educational tool NUCLEONICA was developed. Jointly with FZK training on nuclear forensics was offered on a yearly basis in German language (aimed at experts from German authorities). ITU experts were repeatedly invited by the IAEA to contribute lectures to their training sessions (typically 3-4 sessions per year) related to nuclear security. In the framework of the EU CBRN Action Plan (Action RN.20) JRC-ITU implemented a project (Administrative Arrangement with DG HOME) for setting up a dedicated European Nuclear Security Training Centre (EUSECTRA). Capacity building projects with countries of the former Soviet Union (Russia, Ukraine, Georgia, Azerbaijan, Moldova) were implemented under Admin. Arrangements with DG DEVCO and involved provision of equipment and training of staff (measurement experts, law enforcement, customs etc). A pilot regional project on the

"CBRN Centres of Excellence initiative" was executed between January 2011 and June 2012. The project addressed nuclear forensics issues and targeted the ASEAN countries.

Impacts: ITU's well-established training program in the nuclear security area composed an important pillar for EUSECTRA. Member states authorities (Germany and Finland) were attracted by these training courses and -as a consequence- concluded specific contracts for training their measurement experts in the laboratories of ITU benefiting from the wealth of nuclear material and the diversity of samples available at the Institute. Significant contracts for training were concluded with US DOE.

3.3. Major Highlight(s)

ITU has been co-chairing the Nuclear Forensics International Technical Working Group (ITWG) since 2006. ITU is therefore strongly involved in the organization of the annual meetings of the ITWG. The ITWG brings together experts in law enforcement and nuclear science from some 30 countries and is a forum for exchanging experience and for advancing nuclear forensics. The meetings are attended by more than 60 participants and result in a number of technical guidance documents and performed a nuclear forensics round robin exercise (2010).

German authorities discovered low enriched uranium fuel pellets in a garden in northern Germany. ITU was asked to provide nuclear forensic support. The material was taken to ITU and within one working day a first interim report was issued, detailing that the uranium was of western European origin. In a second interim report (issued one week after sample arrival) the source of the material (a uranium fuel fabrication plant, which was closed down in the late 1990's) could be identified. The case demonstrated the excellent collaboration between ITU and member state authorities, as well as the unique technical competence available within the FACIL action.

In December 2008, the ITU organized a workshop on "Law enforcement and nuclear forensics awareness" jointly with the US Department of State and with the International Science and Technology Centre (ISTC). The workshop gathered law enforcement experts and scientists from Russia, Ukraine, Georgia, Azerbaijan, Armenia, Turkey and Uzbekistan. The workshop aimed at identifying areas for cooperation in this specific area and resulted in a number of specific proposals. The proposals will be funded in a co-ordinated manner by US DOS, the EU (Instrument for Stability) and the ISTC.

The set-up of the European Nuclear Security Training Centre (EUSECTRA) emerged from the EU CBRN Action plan. The need for such a specialized facility allowing for hands-on training with real nuclear material was documented through a "feasibility study" which highlighted in particular the complementarity of such a centre to training provided a national level. A dedicated facility was set up at ITU which includes an indoor and an outdoor training area. A series of pilot training courses was conducted successfully and entailed significant contracts for providing nuclear security related trainings with US DOE, DG DEVCO, DG HOME and most recently with DG TAXUD.

Based on actions RN.13 and RN.14 of the EU CBRN Action Plan, DG HOME tasked JRC-ITU with a project on the improvement of the usability of the IAEA's Incident and Trafficking Database (ITDB). The project closely involved IAEA, Europol and the national points of contact of the EU Member States to the ITDB. The project resulted in a best

practice document for improving the reporting culture and in a web-based reporting tool for the ITDB. The outcome of this project was highly appreciated by the IAEA.

4. Further Information

4.1. Integration and Networking

ITU takes a prominent role as nuclear forensics laboratory on a worldwide level. The Institute is co-chairing the International Technical Working Group on Nuclear Forensics - ITWG - (which reports to the G-8 Nuclear Safety and Security Group). A number of collaboration agreements with national laboratories and international organizations are in place. Nuclear Security activities related to the detection of nuclear and other radioactive material are implemented by IPSC (now ITU Ispra); coordination and joint activities with the relevant actions are carried out. Issues related to nuclear forensic reference materials are closely discussed with the relevant action at IRMM.

Several research and collaboration agreements are established either at JRC level or institute (ITU) level with several partners within and outside Europe.

4.2. Mobility and training of researchers

Fellows Cat 20- PhD: 2

Fellows Cat 30-Post Doc: 1

Fellows Cat 40-Senior Visiting Scientist: 1

Trainees: 13

Invited Persons: 3

EUROPEAN COMMISSION
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Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action *53104 IANUS (AMENUS till 2008)*
Information Analysis for Nuclear Security
Action Leader: *Giacomo Cojazzi (E.08)*

Authorising Officer: *W. Janssens (E.08-Nuclear Security Unit)*
Leading Institute: *Institute for Tramsuranium Elements (ITU)*

0. Policy Area

Policy: 5. Euratom Programme,
Agenda 5.3. Nuclear Security,
Sub-agenda 5.3.2 Open Source Information Collection on Non-Proliferation

1. Rationale of the Action:

Information collection and analysis plays an increasing role in nuclear security in general and in nuclear safeguards in particular. For example under the additional protocol to the non-proliferation treaty, the International Atomic Energy Agency (IAEA) can acquire and make broader use of information well beyond the state supplied declarations.

The action IANUS considers different types of information to deal with nuclear security and proliferation issues and threats, resulting from State and non-State actors. Use and development is made of dedicated information collection and analysis tools for the acquisition and processing of the relevant open source information for deepening the understanding of on-going issues requiring attention and reactions by EU institutions.

Motivated by the EU COUNCIL REGULATION (EC) No 428/2009 of 5 May 2009 and amendments setting up a Community regime for the control of exports, transfer, brokering and transit of dual-use items a focus will be (i) on the identification of information and trade data sources for supporting safeguards verification activities, export controls and non-proliferation studies and (ii) on the design and development of tools to analyse these data.

EC services and EU stakeholders look for unbiased technical information on nuclear security issues. IANUS contributes to this need by monitoring nuclear security issues and proliferation related events. This will form the bases for producing, on the basis of open source information and technical knowledge of the nuclear fuel cycle, non-proliferation studies.

This work is in line with the EU Council Conclusions on “New lines for action by the European Union in combating the proliferation of weapons of mass destruction and their delivery systems (17172/08)”.

Open source information monitoring can provide insights on non-proliferation issues. IANUS is investigating the potential of these sources of information for deepening the understanding of on-going issues requiring attention and reactions by EU institutions.

2. History and development of the Action:

The action Information Analysis for Nuclear Security (IANUS) was created in 2009 as a result of the splitting of the action Assessment Methodologies for Nuclear Security (AMENUS); (AMENUS was one of the four actions created in 2007 for FP7 from the action 3123, Nuclear Safeguards of FP6).

The activities referring to Trade Analysis, Export Control, Open Source Information Monitoring and Nuclear Profiles remained in the newly created IANUS action. The activities on Proliferation Resistance, Systems analysis applied to Security (PR&PP), Safeguards by design (SbD), and Systems Analysis (SA) together with the networking activities i.e. support to European Safeguards Research and Development Association (ESARDA) and European Safety Reliability and Data Association (ESReDA) were merged in 2009 in the action Physical Modelling (PHYMOD) renamed (NUSIM).

In 2011 PR&PP, SbD and SA, activities were transferred back to IANUS, while activities on Export Control were moved from IANUS to NUSIM. From 2010, support to ESReDA was taken by non-nuclear activities. Following the Structure of the 2013 WP, activity on

PR&PP and SbD will be reported here in the action IANUS, Activity on ESARDA and Export Control are described under NUSIM.

3. Description of the Action

3.1. Clients and Stakeholders

Customer/users (outside the European Commission):

- EEAS - European External Action Service
- EU SITCEN - EU SITCEN - EU Situation Centre (renamed EU-INTCEN)
- GIF - Generation-IV International Forum
- IAEA - International Atomic Energy Agency (IAEA)
- US DoE - US Department of Energy (DOE)

Customer DGs (inside the European Commission):

- DEVCO - Development and Cooperation - EuropeAid
- ENER - Energy
- JRC - Joint Research Centre
- RTD - Research and Innovation
- TAXUD - Taxation and Customs Union
- TRADE - Trade

3.2. Major Objectives, deliverables and impacts

Hereafter one overarching objective per working area is presented with a short overview of the activities; related main deliverables are presented for each objective in chronological order followed by description of impacts. Due to changes in the action, objectives correspond largely to those present in the IANUS 2013 action, but do not match completely. Four overarching objectives have been identified to cover all activities here reported. Reports not filed in PUBSY are listed together with non JRC reports resulting from contributions of the action to international activities. The full list of registered entries in PUBSY is reported in section 5.

Objective 1: Trade information analysis for non-proliferation and export control

Data about the world trade are collected by customs authorities and published by States[8] for public use. The data are available from statistical databases (e.g. COMEXT by EUROSTAT, UN COMTRADE by the United Nations) as well as from transactional databases. The objective explored the use of trade data sources in support to i) nuclear safeguards, ii) non-proliferation studies and iii) export controls.

Work for the IAEA started in 2007 in the context of an EC Support Task[9], currently extended until 2015. The task covers both methodological aspects and the development of tools for trade analysis.

DG TRADE is chef –de–file for the EC dual-use Regulation (Regulation (EC) 428/2009 and amendments) implementing export control lists by the Nuclear Suppliers Group, the Missile Technology Control Regime, the Australia Group, the Wassenaar Arrangements and the Chemical Weapon Convention. In 2011 DG TRADE requested JRC to estimate

[8] Respecting national policies on data confidentiality.

[9] Task EC-D-01662, Improving Analysis of Covert Nuclear Trade.

extra-EU trade flows of dual-use items for policy definition and implementation. In 2013 the development of a dedicated tool, the TRADE FLOW tool, for the estimation of extra-EU trade flows of dual-use items was initiated. The tool is based on COMEXT data and a Tableau Software platform.

Starting from 2013, sample trade profiles for selected Third Countries were developed for DG DEVCO in the context of the EU Outreach Programme for export controls. These profiles establish a country's commercial position vis-a-vis the EU, its main partners in trade, and top exported goods.

Institutional activities were reinforced by an Administrative Arrangement signed in 2011 between JRC-ITU and DG TRADE. A MoU signed by JRC and DG TAXUD also identified topics of common interest for future collaboration.

Deliverables
For IAEA

- In the context of the support task to the IAEA, a catalogue of available open source trade databases was established. This resulted in a major report issued in 2007 to the IAEA. The report was updated and extended in 2010 to cover new information sources. The updated report was published as a EURATOM report openly accessible. The report generated high interest from disparate entities around the world who inquired (and continue to inquire) additional information about the trade data services covered in the report.

- The Big Table (TBT) software tool was developed under specific request by the IAEA in order to support their trade analysis activities. TBT is a document search tool which embodies in a database regulatory documents (e.g. the IAEA Additional Protocol, INFCIRC 540 corrected), technical handbooks and the Harmonized System used for customs import-export goods declarations and in trade databases to describe import-export flows (**See figure 1**). TBT is in daily use at the IAEA since 2009. TBT is regularly maintained to cope with updates of documents included in the collection.

- TBT has been delivered also to DG ENER and to 13 EU Member States licensing and customs authorities where it is used for the rating of dual-use goods.

For DG TRADE

- In 2012 JRC provided DG TRADE with upper-bounds of extra-EU exports of dual-use items estimated over a series of years. These estimates were included in the Commission Staff Working Document SWD(2013) 7 final as an indication of the relevance of the dual-use sector in the EU economy.

- In 2013 JRC estimated the EU overall dual-use export value to be 2% of the EU total export, and 2.5 times the export licensed value by Member States. These figures, derived on the basis of statistical customs records (COMEXT data) and export license data collected by JRC from Member States, were published in a Commission report to the Council and the European Parliament on the implementation of Regulation 428/2009 [COM (2013) 710 final, 16 October 2013]. **See Figure 2**.

- Design of a questionnaire to collect license data for dual-use exports from EU Member States. Collection of trade data from EU 27 for the years 2010-2012 and their compilation in a report. The report, limited distribution, was delivered to all EU MS licensing authorities. Aggregated figures were presented in COM (2013) 710 final.

- Estimation of trade flows of dual-use goods to specific countries of interest based on customs data. Presentations to EU member states representatives at the Dual-Use Coordination Group. Limited distribution reports.

- Development of a software tool in support to trade flow analysis.

Impacts

- JRC work on trade analysis contributed to findings on procurement activities of proliferation concern reported by IAEA to its Board of Governors in 2009. Since then the IAEA is using trade data sources and analysis techniques developed by JRC on a regular basis. The IAEA stated that the new approach developed in this support task 'provided very useful results and will be instrumental to the consolidation of information driven safeguards'.

- Estimates of trade flows of dual-use items are needed to inform EU policies of export control. JRC work on trade analysis contributed to have better informed EU policies on export control by estimating the impact of controls on trade. See contribution to Commission report to the Council and the European Parliament on the implementation of Regulation 428/2009 [COM (2013) 710 final].

- A new area of support to DG DEVCO is the import/export profiling of Third Countries for commodities related to strategic trade. These profiles support the selection of countries to be included in the EU Outreach Programme within the Instrument for Stability.

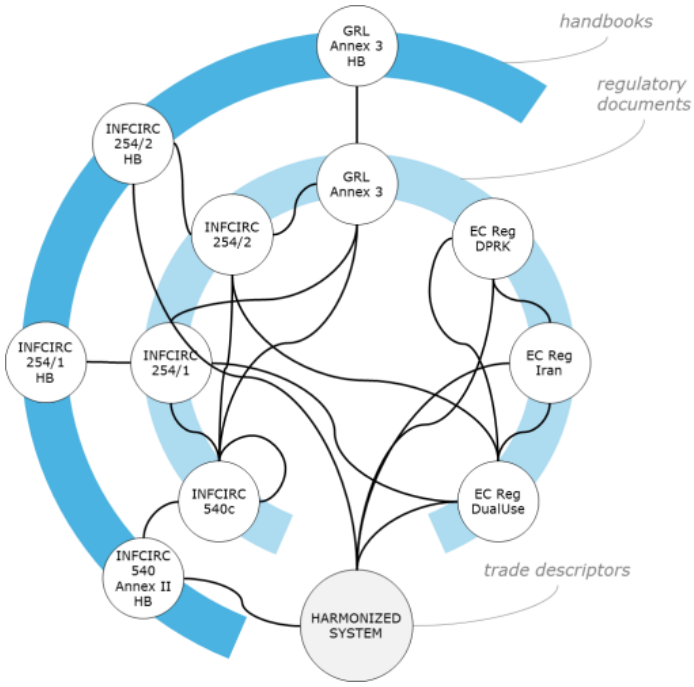

Figure 1. THE BIG TABLE tool relates strategic goods listed in regulatory documents and technical handbooks and descriptors of the Harmonized System used in trade data sources where customs import/export flows between countries are recorded. The figure show part of the nuclear related document collection included in TBT and correspondences among documents.

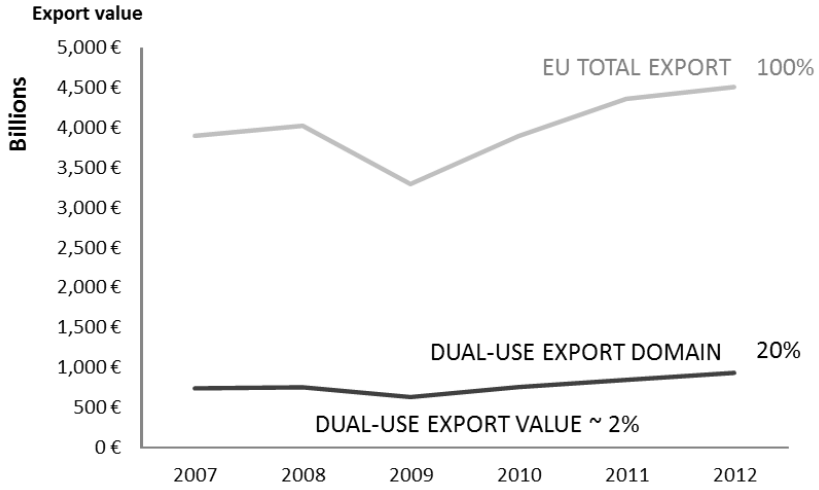

Figure 2. Estimate included in: Report from the Commission to the Council and the European Parliament on the implementation of Regulation (EC) No.428/2009 setting up a Community regime for the control of exports, transfer and transit of dual-use items. COM (2013) 710 final, 16 October 2013.

Objective 2: Monitoring and analysis of open source information

IANUS carries out daily news monitoring and collection on nuclear security issues. Monitored information sources include general news sites, nuclear related sites and databases. The activity supports three aims: i) to investigate the potential of open source in tracking nuclear security issues; ii) to provide input to the generation of non-proliferation studies based on technical analysis and calculations using open source information, satellite images and/or trade data and iii) to provide information awareness and early warning to recipients in the relevant EC and EU institutions.

A JRC nuclear security news compilation is daily issued since 2011 and is widely disseminated to EC and selected EU recipients. Benefitting from JRC knowledge and expertise, the material collected form the basis for more detailed analysis on topical issues.

Studies on non-proliferation issues focused on selected relevant topics and countries of interest. IANUS produced technical commentaries solely based on open source information, trade analysis, satellite images and technical calculations. Resulting studies are normally limited distribution and address areas and topics where JRC can provide added value based on the in-depth technical knowledge of the nuclear fuel cycle.

The activity is aimed to provide unbiased information and technical analysis on sensitive proliferation issues to EU stakeholders. Reports are produced either as notes or scientific and policy reports.

When judged relevant, IANUS products were delivered to Commission services, to the European External Action Service EEAS and to the EU Intelligence Analysis Centre (EU INTCEN, formerly SITCEN), which has been the exclusive civilian intelligence provider to EU decision makers since 2002. To date no MoU exists between JRC and EEAS, for this reason the delivery of products have been done on a case by case basis.

Deliverables

News monitoring and collection

- *Nuclear Security News* compilations based on open source were produced initially for JRC internal use. Starting from 2011 they evolved in a structured newsletter dedicated to nuclear security issues. The newsletter is widely disseminated within European

Commission and EEAS services. During 2013 the newsletter was distributed to about 200 recipients within the EC and EEAS (Recipients were 100 in 2012).

General Studies

- Two reports were produced in 2007. One country profile on the nuclear fuel cycle of Kazakhstan and a report on the **A.Q. Khan Proliferation Network**.

- Reports were issued dealing with **Syria**, after the 2007 bombing of the alleged Al Kibar nuclear reactor at Dair Alzour.

- Various reports on **DPRK** were issued. First one in 2009, after the launch of a rocket by DPRK and before the 2009 nuclear test. Imagery briefs were then issued e.g. on the gas centrifuge facility at the Yongbyon Nuclear complex. More recently, after the DPRK tested a nuclear explosive device in February 2013, reports were issued addressing the power and type of the device (Highly Enriched Uranium vs. Plutonium; this is still an open issue).

- The 2009 Nuclear Agreements with **India**, and developments after the Nuclear Suppliers Group (NSG) deal was the subject of a report issued in 2009.

Iran Studies

- Starting from 2009, particular attention was dedicated to following the evolution of the Iranian Nuclear Fuel Cycle. Since September 2009, IAEA quarterly reports to its Boards of Governors were the subject of JRC technical commentaries. These commentaries follow the structure of IAEA BoG reports, focus being on the Iranian declared nuclear fuel cycle and in particular on its enrichment programme.

- In November 2013, Iran signed with IAEA the so called Framework for Cooperation to address unresolved issues and signed with the E3+3 the Joint Plan of Action (JPA). A specific report was issued on this topic in November 2013. Since then the matter is closely followed as it a main file at international level.

- First commentaries were mainly for JRC Head Quarter (HQ) internal use. Since September 2010, after an internal review process, the commentaries were delivered to the related Commission services. Since 2012 the commentaries were also archived as JRC scientific and policy reports.

- In the period 2009-2013, around 20 limited distribution notes and reports on Iran were issued within the action.

- Modelling activity carried out in collaboration with action NUSIM allowed to gain insights on the behaviour of enrichment process. This was particularly the case for the interconnected cascades that Iran used until January 2014 for the production of up to 20% enriched UF_6.

Support to EEAS & EU-INTCEN

- EEAS and EU-INTCEN are among the main beneficiaries of JRC technical reports and commentaries.

- A workshop with EU-INTCEN, was held in Ispra, on April 26, 2012. The workshop was attended by analysts from EU INTCEN, to present the European External Action Service and the role of EU-INTCEN within EEAS and to discuss JRC support. In the reference period, several drafting meeting were attended and contributed by JRC officers at EU-INTCEN premises.

- Direct support was given to the EEAS, Vienna Delegation to the International Institutions. The delegation represents EU at IAEA Board of Governors events and is responsible to draft the official EU statements at IAEA BoG meetings, including EU statements on Iran Files.

Impacts

- The daily *JRC Nuclear Security News* provide relevant information awareness to a wide range of EU staff working on nuclear security and non-proliferation issues, both at technical level and upper hierarchy. Hence, it indirectly impacts various EU activities such as nuclear security/non-proliferation R&D activities at the JRC; EURATOM safeguards; EU nuclear security and non-proliferation policies.
- Similarly, IANUS' non-proliferation studies provide independent and unbiased technical analysis to interested EU staff and thus have an impact on a wide range of activities. The analysis is delivered directly to relevant stakeholders in the form of JRC reports; it is also further disseminated indirectly, e.g. as feed to reports generated by EU INTCEN and the supporting the work of the EU Vienna delegation.
- The knowledge and expertise obtained from the continuous open-source monitoring and technical analysis of non-proliferation issues allows IANUS to provide valuable ad-hoc advice and briefings to EU stakeholders as required. Examples include: assisting the Vienna delegation in preparing EU statements in IAEA BoG meetings; attending and technically contributing to drafting meetings at EU-INTCEN; briefing the DG JRC before discussing non-proliferation issues with high level external visitors; on-request technical analysis feeding into the EU3+3 discussions related with negotiations with Iran.

JRC limited distribution notes not filed in PUBSY (partial list):

1. Six Notes in the period 2007-2009. (Including a Note on Second Uranium Enrichment Site under Construction in Iran).
2. JRC Note on the IAEA Report concerning the Implementation of NPT Safeguards in Iran and the status of Iran's compliance with Security Council Resolutions 1737, 1747, 1803 and 1835, Draft Compiled by EC-JRC-IANUS, Limited distribution, Delivered to JRC HQ, Feb 28, 2010.
3. JRC Note on the IAEA Report concerning the Implementation of NPT Safeguards in Iran and the status of Iran's compliance with Security Council Resolutions 1737, 1747, 1803 and 1835, Draft Compiled by EC-JRC-IPSC-NUSEC-IANUS, Limited distribution, Delivered to JRC HQ, June 6, 2010.
4. Note on the Announcement by Iranian Dissidents Regarding a New Underground Facility Near the City of Qazvin, 10 September 2010, Released on September 14 2010, Delivered to EC, September 15, 2010.
5. JRC Note on the IAEA Report concerning the Implementation of NPT Safeguards Agreement and relevant provisions of Security Council resolutions in Iran, Compiled by EC-JRC-IPSC-NUSEC-IANUS, 12 September, 2010, Released on 14 September, 2010, Limited distribution, Delivered to EC & Council, September 15, 2010.
6. JRC Note on the IAEA Report concerning the Implementation of NPT Safeguards Agreement and relevant provisions of Security Council resolutions in Iran, Compiled by EC-JRC-IPSC-NUSEC-IANUS, 29 November, 2010, Released on 29 November, 2010, Limited distribution Delivered December 1, 2010.
7. Imagery Brief on the Gas-Centrifuge Enrichment Facility at the Yongbyon Nuclear Complex, December 23, 2010.
8. Imagery Brief on Masyaf, Iskandariyah and Marj as-Sultan (Syria), December 23, 2010.

9. JRC Note on the IAEA Report concerning the Implementation of NPT Safeguards Agreement and relevant provisions of Security Council resolutions in Iran, Compiled by EC-JRC-IPSC-NUSEC-IANUS, 4 March, 2011, Released on 9 March, 2011, Limited distribution, Delivered March 11, 2011.
10. JRC Note on the IAEA Report concerning the Implementation of NPT Safeguards Agreement and relevant provisions of Security Council resolutions in Iran, Compiled by EC-JRC-IPSC-NUSEC-IANUS, 27 May, 2011, Released on 1 June, 2011, Limited distribution, Delivered June 2, 2011.
11. JRC Note on the IAEA Report concerning the Implementation of NPT Safeguards Agreement and relevant provisions of Security Council resolutions in Iran, Compiled by EC-JRC-IPSC-NUSEC-IANUS, 8 September, 2011, Released on 9 September, 2011, Limited distribution, September 9, 2011.
12. JRC Note on the IAEA Report concerning the Implementation of NPT Safeguards Agreement and relevant provisions of Security Council resolutions in Iran, Compiled by EC-JRC-IPSC-NUSEC-IANUS, 14 November, 2011, Released on 16 November, 2011, Limited distribution, Delivered November 16, 2011
13. From 2012, JRC notes on IAEA BoG reports on Iran were also filed in PUBSY.

Objective 3: Information Systems for Nuclear Security

Information collection and analysis plays an increasing role in nuclear security in general and in nuclear safeguards in particular. For example under the additional protocol to the non-proliferation treaty, the International Atomic Energy Agency (IAEA) can acquire and make broader use of information well beyond the state supplied declarations. In this context, IANUS carried our R&D on tools for the collection, analysis and management of open source information[10]. The activities focused on the following areas:

Information collection: The collection and analysis of the vast amount of information published each day on the Internet is an increasing challenge to the open source analyst. Based on JRC's Europe Media Monitor (EMM, developed by the action OPTIMA), IANUS developed tools that are automatically monitoring and collecting information specific to the nuclear security domain and filtering it according to geographic and thematic areas of interest. They aim to improve the efficiency of the information collection process of the open source analyst, for example at the IAEA. In this area, an EC support task to IAEA (EC-D-1880) on "Collection, Analysis and Dissemination of Open Sources" has been activated in 2010. The task has been recently extended till 2015.

Information integration and management: IANUS designed and implemented prototype systems to investigate new concepts for integrated information analysis, focused in particular on the non-proliferation imagery analyst. The concept is centred on a Geographic Information System (GIS) which provides a single point of entry to all available information (spatial and non-spatial) related to a nuclear facility. The activities were mainly carried out in the context of FP7 projects and aimed at improving the efficiency of open source imagery analysis activities at relevant organizations, such as IAEA and the European Union Satellite Centre (EUSC). Based on the experience gained with prototype systems, IANUS developed and continuously populates an open source information system used to support its collection and analysis activities.

Deliverables

- NUMAS is an early prototype, set up in 2007, of the GIS-based information systems. It is integrated with non-spatial information stored in a legacy archive of

[10] For use of trade analysis see objective 1.

open source collected information called “Information Analysis Centre (IAC)” using the indexing capability of the Verity K2 environment. Results were documented in technical reports.

- From 2007 to 2010, IANUS contributed to the FP6 project LIMES developing a GIS-based integration platform for imagery analysts. The platform has been installed for evaluation at the European Union Satellite Centre (EUSC) and the results have been disseminated in various publications. The integration platform has been used and further improved during the follow-up projects G-MOSAIC and G-SEXTANT. (See action NUVER for information on the projects).
- A multi-lingual filter definition targeting nuclear safeguards and nuclear security issues has been defined since 2007 for use within the European Media Monitor (EMM, developed by JRC-IPSC action OPTIMA, which is a web-based multilingual news aggregation system. At 2013 EMM monitors 200000 news articles per day in about 50 languages from more than 4000 web news sources). Based on domain-specific keywords, it selects all relevant articles from the web sites monitored by EMM. The web page is available for both JRC internal and external use. http://emm.jrc.it/NewsBrief/alertedition/en/JRCNuclearSecurity.html
- In collaboration with JRC-IPSC-OPTIMA, IANUS created the Nuclear Security Media Monitor (NSMM) which is a web application that automatically collects and monitors news articles from a pre-defined list of websites. NSMM is based on the generic EMM and is customized to the needs of the nuclear security and non-proliferation domain. It monitors more than 150 nuclear specific web sites (including NGOs, academic, inter-governmental and scientific/technical sites) in addition to general web media sites. NSMM was initially set-up to support the open source analysis activities at IAEA (support task EC-D-1880) and for internal IANUS use. It is now also available to other interested users in the nuclear security and non-proliferation community. The origin of the project, its perspective, current and future uses by IAEA have been the subject of a number of joint JRC-IAEA publications. https://nsmm.emm4u.eu/nucsec.
- The JRC Nuclear News Archive has been developed since 2010 to support IANUS’ open source collection and analysis activities. It is currently in use for integrated management, archival and retrieval of nuclear security relevant information and facilitates collaborative analysis of non-proliferation issues. It is populated with the daily collection of news information with the aim to create an accessible repository of information relevant to non-proliferation. The architecture of the repository and its functionality has been documented in a number of reports and referred in publications. (See **figure 3**, for an overall workflow).

Impacts

- The IAEA is using NSMM during the daily monitoring of its ‘web sources’ (over 150 nuclear-related web sites that were previously monitored manually) which had an important impact on the daily operations of the IAEA Department of Safeguards (Division of Information Management). It has reduced staff allocation, consolidated relevant information repositories into one accessible location, and decreased the block of time needed to collect a full morning collection review.
- The production of the JRC Nuclear Security News is entirely based on NSMM and the Nuclear News Archive. NSMM enables IANUS to generate the JRC Nuclear

Security News very efficiently; the Nuclear News Archive is a valuable asset for subsequent analysis activities.

- The experience gained in the development of the GIS-based integration platform under LIMES influenced the design of equivalent systems at EUSC and IAEA. For example, the Geospatial Exploration System (GES) at IAEA uses similar concepts to provide the safeguards analyst with spatial and non-spatial information related to a nuclear facility.

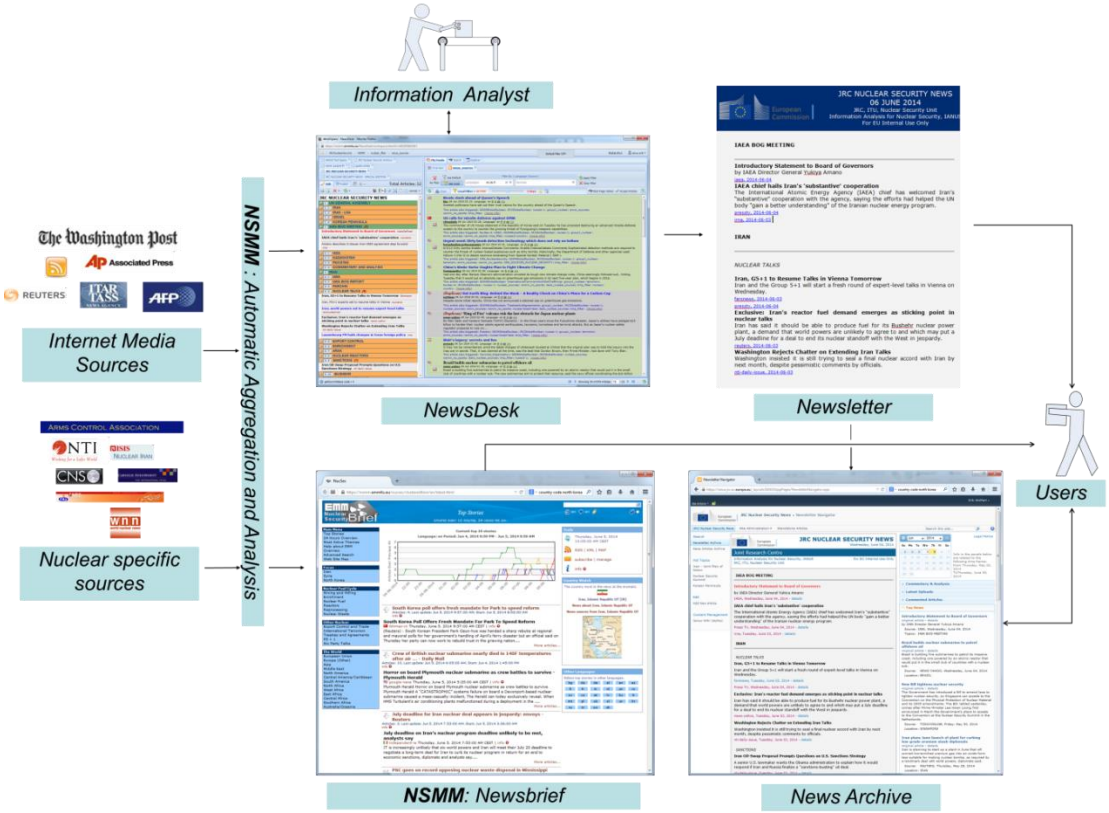

Figure 3. Schematic overview of information flow for the JRC nuclear security newsletter production and archiving for open source information collection and analysis based on NSMM and NewsDesk. NewsDesk is a JRC tool supporting the production of newsletters.

Objective 4: Systems analysis and studies of proliferation resistance of future nuclear systems (Gen-IV) and Safeguards-by-Design

Participation to PR&PP GIF. Proliferation Resistance and physical protection (PR&PP) robustness is one of the areas in which Generation IV reactors need to excel with respect to the existing ones. The action provided representation of EURATOM in the GIF Working Group on “Proliferation Resistance and Physical Protection” (PRPPWG) since its very early stages and actively contributed to its achievements. Participation to PRPPWG is ongoing. http://www.gen-4.org/

Support and contribution to IAEA INPRO. The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), http://www.iaea.org/INPRO/ run by the Nuclear Energy division of IAEA was initiated to ensure a sustainable contribution of nuclear energy to future energy needs. The development of the Proliferation Resistance (PR) and Physical Protection (PP) INPRO manuals published in 2007 was supported and related collaborative projects activated by IAEA since 2008 in the area of proliferation resistance were contributed.

Safeguards by Design (SbD). Safeguards by design is a new concept to consider and promote the consideration on nuclear safeguards in a facility since its early design phases. IAEA initiated a number of activities since 2008, later implemented through the support programme (EC C 1726) with involvement of the Nuclear Energy Division. These efforts were contributed by the action in close collaboration with DG ENER.

Acquisition Paths Analysis (APA). IAEA is revisiting its safeguards state level concept. The identification of possible acquisition paths for a country to acquire weapon usable material will play a major role in it. The action is contributing to an IAEA running support task on APA since 2011 (JNT C 1871). The task is ongoing.

Systems analysis. JRC has long standing experience in systems analysis and risk assessment in the acquired both in nuclear and industrial safety domains. Systems analysis techniques, derived from the safety, were developed for application to the security and safeguards domain. The action ensured support to the European Safety Reliability and Data Association (ESReDA) and the publication of seminar proceedings till 2007. The support to ESReDA was later ensured by other JRC units.

Deliverables

For GIF-PRPP

- The proliferation resistance and evaluation methodology was developed in the course of several years a by means of different revisions, all contributed by the action, culminated in the revision 6, that was made openly available in 2011. It contains i.a. a revision of the PR&PP measures and metrics and a chapter on the use of expert judgment, both contributed by the action.
- A case study analysing the response of an entire hypothetical nuclear energy system, named Example Sodium Fast Reactor (ESFR), has been carried out in 2007-2009, dealing with different proliferation and theft strategies. JRC contribution was in the design of the safeguards system and in the evaluation of the system with respect to the misuse threat. This resulted also in a number of publications.
- As a major joint effort between the PRPP group and the System steering committees of the six generation systems resulted in 2011 in a major report identifying PR and PP features of the six generation IV systems. The action contributed to the compilation of the chapter dedicated to the Lead Fast Reactor system.
- As JRC application of the PR&PP framework, within the 7th Framework Programme Collaborative Project on the European Sodium Fast Reactor (CP-ESFR, 2009-2012), the action led the task on Proliferation Resistance considerations. The task included contributions from AREVA, EdF and ENEA. Results have been reported in a, limited distribution, major project deliverable. The dissemination of non-sensitive results is still under way.

For IAEA

- Manuals developed within IAEA INPRO for Proliferation Resistance and Physical Protection were contributed (both issued in 2007). Comparing and contrasting the PR&PP and IAEA INPRO PR approach has been the subject of several joint GIF & INPRO efforts and publications to which the action has actively contributed (2008-2009).

- The INPRO collaborative project PRADA Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA, 2008-2010) explored the use of acquisition pathways within INPRO PR methodology. The action contributed to the activity and to a number of resulting publications. The INPRO collaborative project Proliferation Resistance and Safeguardability Assessment tools (PROSA), started in 2010, is being contributed.
- On SbD, a kick off workshop was organised in October 2008, at IAEA with main support of EC and US support program (Workshop on Guidelines to designers to facilitate the Implementation of International Safeguards). A generic guideline document issued by IAEA in 2013 has been contributed and a series of facility specific document have been also contributed (first one on reactors which appeared in 2014). Publication by IAEA is ongoing.

For GIF, IAEA, see list of contributed publications not filed in Pubsy.

Safeguardability

- The concept of safeguardabilty, loosely defined as the ease of safeguarding a nuclear facility has been the subject of investigation both within GIF and as a separate JRC effort (2007-2008).
- Within the context of a PhD thesis a systems thinking approach to safeguardability has been explored in collaboration with Bristol University (2008).
- Effects of presence of minor actinides in fresh fuel of sodium fast reactors have been investigated both from the point of view of its proliferation resistance and safeguardability (2012).
- Use of reprocessed uranium in fresh light water reactor fuel was investigated from the point view of proliferation resistance and safeguardability (2012).

Systems Studies

- An ESReDA seminar on Future Challenges of Accident Investigation was hosted at JRC in 2007. Proceedings were published with JRC' Major Accident Hazard Bureau.
- The application of systems analysis to safeguards evaluation effectiveness and to nuclear security has been investigated. Fault tree analysis to safeguards assessment and security issues, entails the need to handle high probabilities related to conditional success probabilities and non-coherent fault trees for the modelling of mutual exclusive events resulting from choices of the attacker. The work resulted in several publications in the period 2007-2012.
- A study on the application of game theory to safeguards inspections planning has been carried out with the Bundeswehr University, of Munich. Organisation of a workshop in 2009 at DG ENER to disseminate the results.
- The advanced, JRC proprietary, Fault Tree analysis code ASTRA-3 was developed along several years in collaboration with other JRC non-nuclear actions. It Implements JRC designed algorithms based on the state of the art Binary Decision Diagram approach and it allows exact calculations of both coherent and non-coherent large fault trees. The code was registered in JRC

software registry in 2012. A version dedicated to security analysis has been also developed (ASTRA-SECAN). A distribution policy will need to be defined.

Impacts

- Within the PRPPWG, JRC contribution is very much recognized by the partners. The methodology is readily available for use within GIF in the context of the system integration and assessment projects. PR&PP final products are made openly accessible through the GIF-PR&PP web site, as a consequence the application the PR&PP evaluation methodology outside GIF is emerging. The maturing of GEN IV designs will trigger further uses of the methodology.
- INPRO documents and guidelines developed within IAEA tasks on Safeguards by Design largely benefitted from the action input (see list of contributions not filed in PUBSY). The process of Safeguards by Design will allow taking into account nuclear safeguards at early design stages: this will increase effectiveness and efficiency of safeguards for new and future facilities.
- Work on application of systems Analysis to nuclear security and nuclear safeguards contributed to the advancement of the related knowledge base. In particular exploring the use of fault tree analysis in security and the development of the JRC ASTRA-3 code which allows performing exact calculations of coherent and non-coherent fault trees.

Contributions to PR&PP main deliverables (partial):

1. PR&PP Expert Group, PR&PP Evaluation ESFR Full System Case Study Status Report, October 2009.
2. PR&PP WG of GIF, Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems, Revision 6, September 15 2011, GIF/PRPPWG/2011/003.
3. PR&PP WG and the SSCs of the, GIF Proliferation Resistance and Physical Protection of the Six Generation IV Nuclear Energy Systems, July 15 2011, GIF/PRPPWG/2011/002.

Contributions to INPRO Manuals and projects:

4. Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual – Proliferation Resistance, IAEA-TECDOC-1575, Volume 5, Vienna, October 2007.
5. Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual – Physical Protection, IAEA-TECDOC-1575, Volume 6, Vienna, October 2007.
6. INPRO Collaborative Project: Proliferation Resistance: Acquisition/Diversion Pathways Analysis PRADA, IAEA-TEC-DODC-1684, IAEA, Vienna, 2012.

Safeguards by Design & CP-ESFR:

7. IAEA, Report on "Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA Safeguards" , Workshop conducted from October 28-31, 2008 at IAEA Headquarters in Vienna, Austria., IAEA-STR-360, February 2009
8. IAEA, International Safeguards in Nuclear Facility Design and Construction, Nuclear Energy Series, No. NP-T-2.8, IAEA, April 2013.
9. IAEA, International Safeguards in the Design of Nuclear Reactors, Nuclear Energy Series, No. NP-T-2.9, IAEA, 2014.
10. C. GARZENNE (EDF), F. BIANCHI, G. GLINATSIS (ENEA), F.M. FUERTES (CIEMAT), C. COQUELET-PASCAL, L. BOUCHER, (CEA), F. ALIM, G.G.M. C0JAZZI, P. PEERANI (JRC), Scenarios of ESFR deployment in Europe, CP ESFR, Collaborative Project for a European Sodium Fast Reactor, CP ESFR – D-SP2.1.1- D2 – revision 0 issued on 20/06/2011 by EDF.

3.3. Major Highlight(s)

- Trade analysis, started in 2007 in support to IAEA, became since 2010 a recognized source of information for safeguards verification activities. The approach was later extended to support DG TRADE in the definition of EU policies and regulations on export control of dual use items.
- Tools (i.a. the software *The Big Table, TBT*) and methodologies supplied by JRC contributed to findings on procurement activities of proliferation concern reported by IAEA to its Board of Governors in 2009 and 2010 (no details can be given for confidentiality clauses). Since then the IAEA is regularly using trade data sources and analysis techniques developed by the action i.a. in the State evaluation process, on the preparation of in-field verification activities, and on discussions with States on safeguards-relevant export data.
- Estimates in the trade flows of chemical, supported DG TRADE in the development of a new Community General Export Authorization on chemicals (2010). JRC estimates on the volume of dual use items were included in a 2013 Commission Document to the Council and European Parliament. COM (2013) 710 final.
- Daily News compilations are produced. Started in 2011 for internal use within the action and then within JRC, they constitute an appreciated source of information regularly used at EC and EEAS. In 2013 they have been distributed to about 200 recipients within EU services.
- Started in late 2009, JRC technical commentaries on IAEA quarterly reports to the BoG on Iran were delivered firstly within JRC and then since fall 2010 within EC and Council services. According to feedback received, they provide EEAS and EU INTCEN analysts with a dependable and unbiased source of information regularly used for their activities. Direct technical support on relevant files was also provided since 2012, support is ongoing (no details can be given here).
- In 2011, the *Nuclear Security Media Monitor* (*NSMM*) has been created as an independent EMM installation and has been customized to the needs of the nuclear security and non-proliferation domain. It provides near-real-time media monitoring on nuclear security issues targeting generic media and nuclear-security-specific sites. After an initial evaluation phase, NSMM went, in 2013, in operational use at IAEA providing a significant efficiency gain in IAEA's information collection workflow.
- Following the development of NSMM and the JRC Nuclear News Archive, the complete production workflow of the JRC Nuclear Security News – including information collection, newsletter editing, dissemination and archiving – uses dedicated tools which ensure an efficient newsletter production and long-term availability of the collected information.
- The GIS-based information integration platform developed under LIMES and the follow-up projects demonstrated an innovative concept for integrated information analysis for nuclear non-proliferation and contributed to improving tools for integrated information analysis at EUSC and IAEA.
- In the area of proliferation resistance and physical protection, the action contributed to major international efforts carried out in the context of the Generation IV International forum Initiatives and IAEA INPRO PR related projects.

Both efforts are still ongoing. Support to IAEA activities on safeguards by design were also a main outcome.

- Developed through a series of revisions, the methodology developed by the Proliferation Resistance and Physical Protection Working Group (PRPPWG) of GIF, was made available for open distribution in 2011. Within the case study carried out in the period 2007-2009 by the PRPPWG on the Example Sodium Fast Reactor, the action provided the safeguards context and carried out together with LLNL of US the analysis of the misuse threat. Several publications highlight the research component of this area of work.
- Work on systems analysis applied to safeguards and security contributed to the advancement of the related knowledge base in the area. The JRC proprietary, Fault Tree analysis code *ASTRA-3* was developed along several years in collaboration with other JRC non-nuclear actions. It was registered in 2012.

4. Further Information

4.1. Integration and Networking

- Internal integration is very important. IANUS benefits from collaboration and integration with several action actions of the Unit, in particular NUSIM and NUVER.
- Collaboration with JRC-IPSC non-nuclear action OPTIMA was fundamental for setting up the nuclear security media monitor.
- Work on Systems Analysis methods and tools was developed in collaborations with JRC-IPSC (actions MAHB and CIP).
- Participation at the Dual Use Consultancy Group set under the Article 23 of the EC dual use regulation allows networking with the EU Members States licensing officers.
- The activities on Trade analysis and open source are very well connected and linked to the IAEA through the EC support programme.
- Networking in the field of nuclear proliferation resistance is ensured by the participation to GIF PR&PP and IAEA-INPRO activities. Safeguards by design and acquisition paths analysis activities are carried out in the context of the EC support programme to IAEA.
- JRC was among the founder of European Safety Reliability and Data Association. ESReDA Proceedings have been published by the action till 2007. ESReDA networks JRC with the safety and reliability community for nuclear and non-nuclear applications.
- For ESARDA (secretariat, symposia, web site, Bulletins): see NUSIM action. The action IANUS supports the activity of the ESARDA's Verification Technologies and methodologies working group and of the Implementation of Safeguards working Group.

4.2 List of Competitive Activities

Support to Commission (AA's with customer DG), main competitive activities of the unit E08 portfolio contributed:

DG TRADE 32608. AA on: TECHNICAL SUPPORT IN THE FIELD OF DUAL-USE EXPORT CONTROLS. The action is responsible for the strands 2 (Trade flows analysis) and 3 (Development of export control tools).

DG DEVCO: 32653 ESF: Management of an Expert Support Facility to implement projects of the Instrument for Stability.
32877 Support to CBRN-CoE. Major contributions in the area of Needs Assessment (Development of questionnaire; mission to countries, etc.).
33125 CBRN-CoE 3rd round. Contributions in the areas of open source, trade analysis.

Indirect Actions (participation to FP6/FP7 projects)

EISOFAR (*EURATOM FP6 Specific Support Action, 12 months, concluded*)
Project executed in 2007-2008 to establish a Roadmap for a European Innovative SOdium cooled FAst Reactor. 17 partners contributed to this project, including research institutes, universities and industry representatives. The action contributed to the project with the definition of the requirements for proliferation resistance.

CP-ESFR (*EURATOM FP7 Collaborative Project, 4 years, 2009 - 2012*)
Collaborative Project on the European Sodium Fast Reactor (25 partners, including JRC), aiming at carrying out the R&D plan defined by EISOFAR. ITU E08 lead the task related to providing proliferation resistance and physical protection (PRPP) considerations and contributed to the task related with scenarios development for the PR issues.
For FP6 project LIMES, and FP7 projects G-MOSAIC and G-SEXTANT, see action NUVER.

4.3. Mobility and training of researchers

- Two staff members of the action have been on long term missions to DG AIDCO and RELEX respectively in 2007 and 2008-2009. This contributed to start the implementation of the Instrument for Stability project and to launch a number of related activities.
- Large part of the action activity is implemented by temporary staff and grant holders.
- One PhD thesis was done in the reference period.

5. Other Information

5.1. Patents and Licenses

The JRC The Big Table software has been registered in 2011 in the JRC software registry (2823).
The JRC software ASTRA 3 has been registered in 2012 in JRC software registry (2920).
The JRC software ASTRA SECAN has been registered in 2012 in JRC software registry (2921).

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action *53105 - NUVER*

Nuclear Facilities Verification

Action Leader: *J. Gonçalves (2007-2009) / V. Sequeira (2009-2013)*

Authorising Officer: *W. Janssens (E.08-Nuclear Security Unit)*

Leading Institute: *Institute for Tramsuranium Elements (ITU)*

0. Policy Area

Policy: 5. Euratom Programme,
Agenda 5.3. Nuclear Security,
Sub-agenda 5.3.1 Nuclear Safeguards, Additional Protocol and Combating Illicit Trafficking

1. Rationale of the Action:

There is a constant need to "staying ahead of the game" in all security application areas, including Nuclear Safeguards. The evolution of Information and Communication Technologies - ICT - is a major driving factor for better and/or improved equipment and tools. This constant evolution is based on new/improved sensory devices and tools, including data and information processing, analysis and management. NUVER's vision believes that ICT, in their widest sense, will play ever increasing and strategic roles in the design of future Safeguards and Security instrumentation and monitoring equipment, and that Safeguards and Security needs raise challenging issues in data processing, analysis, visualisation and management. Targeted research, technology selection and efficient System's Integration are key factors for the successful implementation of future Safeguards approaches.

Guided by a vision of ICT developments, and the understanding of users' needs in the Safeguards community, NUVER carries out R&D to identify and test new sensors and techniques (e.g., containment, surveillance and environment modelling devices) as well as to develop monitoring tools for the different parts of the fuel cycle, including efficient data review and information management.

The tools developed can be integrated into intelligent monitoring systems involving remote data transmission and review. Indeed, intelligent monitoring and enforcement systems offer the ability to detect and timely document events by equipment that operates in unattended mode for long periods of time. Here, there are needs for tamper proofing and data authentication that can be met by new system-design approaches. When authenticated, data from nuclear operator's owned follow-up and control systems can be directly used by Safeguards authorities.

Along the above lines, NUVER works on the provision of geometrically accurate (i.e., 3D) models of nuclear installations, both indoors and outdoors. These models are the basis for (a) creation of baselines for facilities entering or re-entering Safeguards as well as (b) the provision of 3D maps indicating where changes occurred. Authorities and independent R&D labs have confirmed the utility of NUVER work of recent years in Safeguards. This gives ground for expansion in more targeted, user-defined, applications, going beyond the existing demonstration prototypes. Areas of future R&D include the integration of data associated to a particular environment (e.g., radiation, thermal) as well as exploring new modalities for accurate outdoor modelling.

Current needs and emerging technologies provide opportunities to "raise the bar" for containment and surveillance devices. A specific area for the continuation of R&D work is the use of 3D surface maps as a way to uniquely authenticate objects of relevance for Safeguards, namely nuclear containers, including UF6 drums, plutonium cans and dry storage casks. Both DG ENER and IAEA express increasing interest in this technique.

The Additional Protocol provides the legal framework for a new investigative role for the nuclear inspector including the possibility for unannounced inspections. In order to

improve the effectiveness of this new role, the inspector needs to be equipped with a new generation of tools and instruments allowing on-the-spot measurements, augmenting her/his verification skills, as well as the capability to access relevant Safeguards data and information in the field. Indeed, within the context of complementary access visits information requirements cannot be exhaustively planned before the inspection as the focus of the inspection needs to adapt dynamically to local findings. This framework requires the ability to relate what is "seen and measured locally" with information existing in headquarters' databases, remote sites and on-line services. This is an area where there is a need for effective application-oriented demonstrators. The approach to be followed relies on the combination and smooth integration of technologies (e.g., virtual and augmented reality, mobile communications, indoor and outdoor positioning devices, etc.) and a perfect tailoring to inspector/inspection needs.

NUVER developed tools for the efficient and intuitive integration of information from multiple sources, resolutions and time-frames mainly based on the use of Geographical Information Systems. This lead to further development work for DG ENER and IAEA inside IANUS action.

Training activities represent the key for the efficient deployment of new technologies. NUVER incorporates training activities as part of all its field-deployment exercises.

Finally, NUVER is heavily engaged in the dialogue between researchers and end-users, including DG ENER and IAEA staff, Member States' authorities and relevant research laboratories (as part of partnerships). International collaborations are important for maintaining awareness of developments and methods in sister laboratories, as well as for dissemination and cooperation. International actors with whom NUVER is related include: ABACC, US DoE laboratories (INL, ORNL, LBNL, LLNL, SNL), ESARDA Working Groups (i.e., Verification Technologies and Methodologies, and Containment and Surveillance).

2. History and development of the Action:

The VERTEC Action (Verification Technologies and Methodologies for Nuclear Safeguards and Additional Protocol) started in 2007 (as one of the four actions that resulted from the split of the FP6 Action 3123 on Nuclear Safeguards and Non-Proliferation). In 2009, the action was renamed NUVER – Nuclear Facilities Verification, with no major orientation changes.

3. Description of the Action

NUVER aims at contributing to future Safeguards approaches and applications by doing ICT (Information and Communication Technologies) related R&D work on verification tools and techniques (for containment, surveillance, and environment modelling devices). This is achieved by bridging the gap between selected technologies and final, user-defined, Safeguards application goals. Success in this requires continuous dialogue between researchers and end-users, including DG ENER and IAEA staff, Member States' authorities and research laboratories

3.1. Clients and Stakeholders

Customer/users (outside the European Commission):

- ABACC
- IAEA
- Member States
- Member States Administrations (e.g., STUK)
- Member States Research Organizations (e.g., CEA)
- CEA (within the framework of the CEA-JRC agreement)
- US DOE (within the framework of the DOE-EURATOM agreement for collaboration in the field of Nuclear Safeguards and Security)

Customer DGs (inside the European Commission):

- EuropAid - DEVCO
- External Relations - EEAS
- Energy - DG ENER

3.2. Major Objectives, deliverables and impacts

The structural projects upon which the VERTEC/NUVER action is based are described below. They are presented in an aggregated form, i.e., as seen from the 2007-2013 FP7 context (not yearly based). All projects include the necessary training actions for both inspectors and operators. For each project, a list of the most relevant Deliverables for the 2007-13 period is included. An Impact statement is also part of the overall description.

Project 3D C/S and Identification Technologies:

The project investigates and develops tools for 3D laser based identification and self-authentication (i.e., fingerprinting) of nuclear components with Safeguards relevance (e.g., containers, transportation flasks, fuel assemblies, etc.). The technique is based on the principle that at very high 3D measurement accuracy (order of microns) it is virtually impossible to replicate a surface, hence the fingerprinting aspect. The project supports DG ENER and IAEA in their efforts to (a) authenticate, (b) verify the integrity of and (c) uniquely identify objects with Safeguards relevance. Developments and implementations include: (i) System to identify UF6 cylinders at an enrichment plant (see highlight); (ii) Prototype for the verification of integrity of large containers – a few metres long; (iii) System to authenticate the welding seams of Plutonium cans; (iv) System guaranteeing the secure detection of unauthorized access to a European Plutonium storage site.

Deliverables:

2007.01: Prototype for IAEA field trial at a nuclear enrichment installation in Japan

2008.01: Mechanical setup and software for 3D scanning and verification of the surface of large nuclear containers

2008.02: Provision of new Laser Item Identification System: L2IS (based on the results of the IAEA field trial at Enrichment Plant) for UF6 real-time container identification and authentication, including IAEA field installation and testing

2009.01: Update and field-trial of the Laser Surface Mapping System for Containment Verification (LMCV) for the IAEA, including a feasibility study on the use of a

hand held scanner for the inspection of a random surface area on large containers - Task IAEA EC-E-01549

2009.02: Submission to a relevant, peer-reviewed journal of an article on the evaluation of calibration approaches of laser-triangulated sensors

2009.03: Field installation and testing of a laser based 3D system for verification of the integrity of a separation grid on a smoke duct at Sellafield Product and Residue Store (SPRS) - DG ENER request

2009.04: Study of Feasibility for the utilisation of 3D laser based surface mapping technologies for the identification of fuel rods content in a magazine, including the verification of the number of items stored as well as those entering and exiting the processing room - IAEA request (JMOX project)

2010.01: PuO2 Storage: Prototype 3D identification – Demo at SPRS Sellafield

2010.02: Generalised toolbox for surface authentication, with improved statistical analysis for better discriminant performance, for new L2IS software REP Japan.

2010.03: Prototype of a 3D surveillance system based on IAEA's Next Generation Surveillance Camera (NGSS)

2011.01: Report on the implementation, in-house testing and early in-field tests of the prototype laser system to identify Pu cans for the PuO2 Storage in Sellafield. DG-ENER Task.

2011.02: Prototype of a laser based OCR system for the Sellafield Product and Residue Store (SPRS). DG-ENER Task.

2011.03: Prototype of a laser based surveillance system for Spent Fuel ponds in Japan. Developed within IAEA Task: EC-A-01634 MSSP Umbrella Task - Support for Novel Technologies.

2011.04: Prototype for the Authentication and Integrity check of Dry Storage Containers (DSC) in Canada. IAEA Task EC-E-01549 - 3D Laser Surface Mapping of Canister Closure Welds.

2011.05: Demonstrator of the 3D surveillance system integrated with NGSS - IAEA Next Generation Surveillance Camera. IAEA Task. EC-E-01636 Software Engineering Support for 3D Camera Development.

2011.06: Software and hardware updates, Documentation, Technical Reports on data evaluation, and in-field support for the L2IS system installed in Japan at Rokkasho Enrichment Plant. IAEA Task: EC-E-01696 L2IS: Laser Item Identification System.

2011.07: Patent on Method for Safely Identifying Moving Objects - Related with the L2IS. International Patent application filed with ID:PCT/EP2011/062177

2011.08: Peer reviewed paper submission on laser surface authentication techniques.

2012.01: Report on the testing of the laser based OCR system in the Sellafield Product and Residue Store (SPRS).

2012.02: Installation, Documentation, Technical Reports on data evaluation, and in-field support of the tailored made light-weight laser triangulation scanner system for the verification of the separation grids on the ventilation stacks of the Sellafield Product and Residue Store (SPRS)

2012.03: Feasibility study and early prototype of a system to identify the drums on the Sellafield THORP UO3 Store Weighing Station.

2012.04: Final system assembly, Documentation, Technical Reports on data evaluation, and in-field support for the laser based system (LMCV) for Authentication and Integrity check of Dry Storage Containers (DSC) in Canada. IAEA Task EC-E-01549 - 3D Laser Surface Mapping of Canister Closure Welds.

2012.05: Software and hardware updates, Documentation, Technical Reports on data evaluation, and in-field support for the L2IS system installed in Japan at Rokkasho Enrichment Plant. IAEA Task: EC-E-01696 L2IS: Laser Item Identification System.

2012.06: Test support and updates of 1st generation prototype integrated with IAEA's Next Generation Surveillance Camera. Research and Technical Report on the use of alternative 3D time-of-flight sensors. IAEA Task EC-E-01636 Software Engineering Support for 3D Camera Development.

2012.07: Publication on the LMCV system

2013.01: Scientific Publication on the laser mapping for containment verification system algorithms

2013.02: Support to DG ENER on the laser based systems developed to the Sellafield nuclear reprocessing site mainly for the Sellafield Product and Residue Store (SPRS) for Integrity checking of the separation grids on the ventilation stacks. The deliverable includes field Support and data evaluation technical reports.

2013.03: System specification for a laser based surveillance system (LaSSy2) for a spent fuel storage pond in the nuclear fuel reprocessing plant of AREVA in La Hague (France).

2013.04: Final system specification for the laser based system (LMCV) for Authentication and Integrity check of Dry Storage Containers (DSC). IAEA Task EC-E-01549 - 3D Laser Surface Mapping of Canister Closure Welds.

Sub-Project Vulnerability Assessment (VA) of IAEA's Next Generation Surveillance System (NGSS): IAEA Task: EC-E-01830

Deliverable:

2012.01: Classified Report

Impact:

This project had a huge impact. Two systems (L2IS in and LMCV) were authorized by the IAEA for routine safeguards use in November 2012 and April 2013 respectively. DG ENER is using a tailored system in support of the periodic Basic Technical Characteristics (BTC) verification in Sellafield Product and Residual Store (Safeguards by Design). Further applications are currently under investigation both by IAEA, i.e., Republic of Korea, Pakistan and DG ENER, i.e., Cernavoda (RO). All this reveals a wide confidence in the potential of the technology as well as in NUVER integration and engineering capabilities.

Project 3D Site Monitoring and verification: The project uses 3D (i.e., distance measurement) technologies to create “as-built” accurate models of nuclear facilities. There are four main uses for these models: (a) geometric and photo-realistic description/representation of a site, both indoors and outdoors; (b) detection of changes, e.g., pipework – to ensure that the plant operation intent is as declared; and (c) presentation tool to combine/fuse/integrate plant related information and data (i.e., high-resolution 3D models (indoor, outdoor), simplified 3D CAD models, maps, vector information, text information, pictures, satellite images - visible, hyper-spectral, SAR, etc. - or any other information, e.g. radiation, thermal maps, GPR - Ground Penetrating Radar) onto a single model – easing access, interpretation and analysis and finally (d) training of inspectors and preparation for inspections – the models provide the necessary and realistic feeling of “being there”. Activities include (i) Verification of Design Information (DIV) for Safeguards purposes (see highlight); (ii) combination of 3D geometric models with radiation maps (together with some US-DoE laboratories); (iii) development of tools for fast and easy 3D outdoor modelling of nuclear facilities.

Deliverables:

2007.01: Second generation of a semi-automatic vehicle borne acquisition system

2008.01: Report and demonstration to the IAEA of the new Outdoor Verification System

2009.01 Submission to a relevant, peer-reviewed journal of an article on large-scale model data fusion based on the error-bound concept

2009.02: New software package, including training, for IAEA's DIV Tool based on the technology of Reconstructor-2, including new data authentication procedures and the capability to map digital and gamma ray images - Task IAEA EC-E-01425

2009.03: Software package for the fusion of security sensor data (i.e., Gamma radiation, X-Ray) and CAD models with 3D modelling of objects, aimed at a dedicated field tool to be developed in collaboration with France's CEA – Task Sheet of JRC-CEA agreement

2009.04: Development of new 3D reconstruction techniques using data acquired (laser scanner and cameras) from a Zeppelin aiming at a fast and cost-efficient 3D mapping of wide areas for urban security applications

2010.01: Algorithms on Automatic Registration – Paper published on peer-review 3D Research Journal

2010.02: 3D Change Detection using a Projective Point Transfer Function –Peer-review paper submission 3DPVT

2010.03: Peer review paper Scene Representation and Model Fusion, submitted to IJRR Journal

2010.04: Foundation created. Peer reviewed paper on Registration using 3D lines published in IEEE ICIP Conference

2010.05: 3DLVS Software + Training + Paper INMM

2010.06: Software package for the fusion of data (gamma, X-Ray, laser)

2010.07: Support to the SOLO action: JRC 3D Reconstructor, training and assistance

2011.01: Plug-in for management of data from large sites in the new generation 3 DLR systems. Report on Field test. IAEA Task: EC-E-01425 3D Laser Range Finder for Design Verification.

2011.02: Training course on the use the Next Generation 3DLR system for IAEA and DG-ENER. IAEA Task: EC-B-01844 Training of Safeguards Inspectors 3DLR (3D Laser Range Finder).

2011.03: Field trial on an ABACC facility of the combined Laser and Gamma system and corresponding Technical Report. Action Sheet 35 with US-DoE (ORNL, LLNL, LBNL) and ABACC

2011.04: Prototype of precise object localisation software. Classified CEA-JRC Report. Task-Sheet on 3D Technologies for Security Emergency Response part of the JRC-CEA Security Research agreement.

2011.05: Three peer review paper submissions on novel algorithms for 3D data analysis and processing.

2012.01: Analysis, Scanner Control and Data Management Software, Documentation and Firmware development support for Next Generation 3DLR system (3DLC) for IAEA. IAEA Task: EC-E-01425 3D Laser Range Finder for Design Verification and New task to be defined.

2012.02: New training material and course on the use the Next Generation 3DLR system (3DLC) for IAEA. IAEA Task: EC-B-01844 Training of Safeguards Inspectors 3DLR (3D Laser Range Finder).

2012.03: Combined 3D laser scanner and gamma-ray imaging system. Final report and future recommendations. Action Sheet 35 with US-DoE (ORNL, LLNL, LBNL) in collaboration with ABACC

2012.04: Release versions of the data fusion software for precise object localization and detector alignment. Classified CEA-JRC Report on the data fusion experiments. Task-Sheet on 3D Technologies for Security Emergency Response part of the JRC-CEA Security Research agreement.

2012.05: Peer review paper submission on Mutual calibration of 3D point clouds and X rays images

2012.06: Peer review paper submission on novel algorithms for 3D data analysis and processing: Descriptors for Partial Matching;

2012.07: Peer review paper submission on 3D large database handling

2013.01: Scientific publication(s) on novel algorithms for 3D data analysis and processing

2013.02: 3DLR Software and Documentation updates

2013.03: Training of Safeguards Inspectors (5 days, 10 participants)

2013.04: Field Support and data evaluation technical reports.

2013.05: 3D system for fast mapping of geological repositories.

2013.06: Task-Sheet on 3D Technologies for Security Emergency Response part of the JRC-CEA Security Research agreement. Support to CEA on their operational version of the software and work on general improvement of the algorithms.

Impact:

This project had a high impact, namely for the Design Information Verification – DIV – problem. Indeed for the first time since the introduction of Nuclear Safeguards there is a tool that can automate the change detection process in a highly reliable and efficient process. The IAEA started using this tool in 2003 and authorized for routine safeguards use in November 2012. DG ENER acquired two systems in 2010 and uses it for periodic Basic Technical Characteristics (BTC) verification in Sellafield Product and Residual Store and support for the PIV of the Material Park in AREVA NC Pierrelatte. The same technology was demonstrated to ABACC in 2008 and a technology transfer is underway following the administrative arrangement signed with DG DEVCO in the end of 2012. Finally, following a bilateral JRC-Finland collaboration, NUVER created in June 2007 an accurate 3D model of the Onkalo tunnels (2.2 Km) – a Finnish geological test site for the final repository of spent fuel. The IAEA and DG ENER used the experience from this work to the creation of a new approach for Geological Repositories.

Project Integrated Remote Operation and Monitoring: The project develops a software toolbox for the design, simulation, real-time remote monitoring and operation of advanced surveillance systems for safeguards purposes. Surveillance case studies proposed by DG ENER and IAEA are used to test the functionally of the toolbox. It further includes the capability to simulate radiation sensors extending the applications to external detection triggers for surveillance and to nuclear security training. The project further supports the assessment of safe and reliable techniques for view of the retrieval of spent nuclear fuel (SNF) at Andreeva Bay, Russia. This includes a 1:1 scale experimental trial at the RIALTO laboratory aiming at validating the specifically designed equipment prior to the retrieval of the nuclear spent fuel assemblies. The project stopped in the end of 2010.

Deliverables:

2007.01: Safeguards Design and Simulation tool for Surveillance Applications – proof of concept

2008.01: Prototype demonstrator integrating: (a) easy-to-use 3D graphical modelling or sketching tools of areas to be safeguarded; (b) a software library for 3D simulation of surveillance systems;

2008.02: Report on the experimental trials carried on special tools and devices for the retrieval of Spent Nuclear Fuel at Andreeva Bay

2009.01: Set of user manuals on the safeguards simulation tool software application including advanced functionalities for evaluating the vulnerability of surveillance systems

2009.02: Submission to a relevant, peer reviewed journal of an article on Tele-operation with haptic feedback - including a methodology for the calibration of tactile sensors. □

2010.01: Prototype system of a VR toolbox tailored to the specific needs of SeTraC (JRC Security Training Centre) and Technical report

2010.02: Workshop on JRC Spent Fuel retrieval experiments: Presentation and technical discussion of all JRC studies and tests performed for Andreeva Bay

Impact:

The concept and demonstrators of the Safeguards Design and Simulation tool, even if at an early stage of development, are proving to be successful within the Safeguards Containment and Surveillance community, namely, ESARDA C/S Working Group. Both DG ENER and IAEA have been most supportive in defining realistic scenarios to test the concept as well as for testing the embedded software capabilities. This became object to the EC-SP task for the IAEA EC-B-01876 Development of Virtual Reality Tools for Safeguards Training. These concepts have been picked up for training purposes within the framework of the new Nuclear Security Training Centre hosted at JRC-ITU: EUSECTRA. Indeed, a few interactive demonstrations have been prepared to simulate the routine work of a customs guard when performing a thorough inspection of a truck suspected of having radioactive substances on-board. The Andreeva Bay project, coordinated with UK's Dept. of Energy and Climate Change, became more challenging than initially foreseen. Indeed, the physical storage conditions of spent fuel are such that required a major effort to develop dedicated robotised tools for their retrieval and manipulation. Prior to their field deployment there was the need to simulate and test these tools as well as defining the appropriate operational procedures.

Project Audit Methodology in Safeguards: The project supports DG ENER in the different phases – discussions, specialist field audit tests, writing and associated training for Safeguards authorities and nuclear operators – development of the Commission recommendation for NMAC (Nuclear Material Accountancy and Control) systems.

N.B. Following the publication in February 2009 of the Commission Recommendation upgrading EU guidelines for quality assurance in NMAC systems throughout the fuel cycle (see highlight). This project stopped in 2009.

Deliverables:

2007.01: Provide training documentation for DG ENER that synthesises the audit approach emerging from the work of the trial audits and the discussions in the framework of the ESARDA Focus group

2007.02: Assist the ESARDA Audit Focus Group by contributing as required to the elaboration and adaptation of guideline documents dealing with NMA best practise and audit requirements. Participate in the Focus Groups dissemination of its work.

2008.01: Preparation of Commission recommendation following DG ENER's consultations with Member States and nuclear operators

2008.02: Participation in trial audits at the request of DG ENER

2008.03: Assist ESARDA by contributing as required to the elaboration and adaptation of guideline documents dealing with NMA best practice and audit requirements, including relevant training activities

2009.01: Seminar's and training courses for an effective and smooth dissemination of Commission audit approach and recommendation

2009.02: Assist ESARDA by contributing, as required, to the elaboration and adaptation of facility specific guideline documents dealing with NMA best practise and audit requirements, including relevant training activities

Impact:

The impact of this project can be measured by the fact that the European Commission, after discussions with EU member states, published an official Commission Recommendation for quality assurance of operators' NMAC systems – Nuclear Material Accountancy and Control. These guidelines represent an important milestone in the ongoing dialogue between EU member states and the Commission on the objectives of audit and its role in the Euratom safeguards system. The characteristics of operator NMAC systems are also important for the EU/IAEA discussions regarding the application of Integrated Safeguards within the EU.

Project Treaty Verification Tools/ Information Integration Tools: The project aimed at increasing the effectiveness and efficiency of the verification of treaty compliance. Close collaboration with both DG ENER and the IAEA ensured the developments are in-line with the integration and management of information related to nuclear facilities and in compliance with additional protocol requirements. The tools enable the efficient integration, analysis and presentation of information from different sources (sensory, textual, imagery, GIS, 3D Models, etc.). In 2009 the project began investigating the usefulness of earth observation tools for safeguards purposes. The project stopped in 2011.

Deliverables:

2007.01: Installation of SIT-ES within a secure network at DG ENER in Luxembourg [SIT-ES supports DG ENER/H in the management and verification of AP declarations and DG ENER/I in planning and analysing on-site inspections.

2008.01: SIT-ES will be extended to support all articles of the Additional Protocol and other entities identified by DG ENER. The developments will be fully documented, validated and installed in the DG ENER operational environment

2008.02: Development and demonstration of GIS-based integrated information platform for Treaty Monitoring within the LIMES FP6 project

2008.03: 3D GIS Interface. 3D GIS interface to JRC 3D Reconstructor and Verificator (3D change detection), including installation and training at IAEA's Satellite Image Analysis Unit

2009.01: Extension of SIT-ES to include additional information sources specified by DG ENER. The developments will be fully documented, validated and installed in the DG ENER operational environment

2009.02: Support the IAEA for the specification and demonstration of a Safeguards department-wide GIS - Task EC-D-01664: Software-Hardware and Database Provision for Satellite Imagery

2009.03: Report on the utility of medium and low resolution earth observation for non-proliferation studies - Task JNT-D-01657: Signatures of Nuclear Fuel Cycle Related Processes

2010.01: Specification and installation at IAEA demonstrator info multiple sources

2010.02: Applying Computer Vision technologies for satellite imagery analysis in Nuclear Safeguards.

2010.03: Detailed analysis of the potential of EO imagery and products to sensitive areas for which ground truth already exists".

2011.01: Review of automated satellite image analysis techniques applied to nuclear non-proliferation monitoring.

Impact:

The introduction of the Additional Protocol (AP) created a legal mechanism for the IAEA to access data and information that goes beyond the classical measurement based Safeguards. This raised the issue of how to manage the wide variety of information and let them be analysed in an efficient way. In this context, NUVER developed novel concepts, demonstrators and operational systems to manage and analyse information of different types (e.g. textual, numerical or spatial information) distributed over different sources (e.g. different databases, web-applications or network locations). With this work, NUVER helped improving the efficiency and effectiveness of its customers – DG ENER and IAEA – in analysing and verifying Safeguards related information.

Project Safeguards Review Station: The project develops tools to assist inspectors in the efficient and accurate review of surveillance video-streams. Several machine learning techniques are used to identify 'recurrent-type' events in the data reviews (based on plant's historical data, previous reviews and machine learning technologies). In 2009 the project started investigating the use of summarisation techniques for 'one-off' type of reviews. Further, the project investigated in close collaboration with DG ENER the applicability of the Enhanced Data Authentication Platform, a concept developed by US Sandia Laboratories, enabling the authenticated use of facility owned sensory data by Safeguards inspectorates.

Deliverables:

2007.01: Integration of a Markov-based tool for consistency verification of event streams in Safeguards image sets with MiniGARS++

2007.02: Technical specifications and support for the integration of DCM14 cameras into DG ENER’s RADAR/CRISP system.

2008.01: Report on approaches for data summarization and their applicability in Safeguards

2008.02: Joint report (US-DOE, DG ENER, DG JRC-IPSC) on the use of the Secure Sensor Platform in Safeguards (Action Sheet DOE-EURATOM Agreement)

2009.01: First demonstrator on information visualisation and data summarisation and their applicability in Safeguards

2009.02: Submission to a relevant, peer-reviewed journal of a comprehensive article describing the project's R&D work in the field of search and retrieval of surveillance images by content and metadata attributes

2010.01: JRC Technical Note on summarization techniques

2010.02: Second demonstrator (software)

2011.01: Enhanced demonstration system.

2011.02: Articles for the ESARDA Bulletin and INMM 2011 Annual Meeting.

2011.03: JRC Technical Note on similarity-based learning applied in the context of image summarization; Depending on the quality of the results, a peer-review article might be submitted.

2011.04: Third demonstrator (software) on information visualisation and data summarisation including similarity-based machine learning.

2012.01: Training/Evaluation of VideoZoom by DG ENER and IAEA's Inspectors

2013.01: Fourth software demonstrator on video summarisation for safeguards image reviews.

2013.02: Scientific publication on testing the fourth software demonstrator on safeguards videostreams.

Impact:

The low cost and wide availability of surveillance devices (including the capacity to store sequences of images with a short picture taking interval) puts pressure on reviewing capabilities. NUVER algorithms and methods proved to be more efficient than traditional scene-change detection based reviewing methods. In collaboration with DG ENER and IAEA Surveillance experts, tests made with real Safeguards video streams showed it is possible to reduce the reviewing effort, namely when events are recurrent – which is often the case for many installations under Safeguards. This means that inspector's time is better used as s/he needs to review a reduced number of images, while ensuring all Safeguards relevant pictures are presented for review.

The project also covered until 2011 the use of the Secure Sensor Platform for Safeguards applications, together with DG ENER and Sandia Labs. The major impact of this type of sensors is providing the security guarantees enabling the use by safeguards authorities of plant operator owned sensors and devices. These sensors complement those installed by Safeguards authorities at a minimum cost as all the installation and maintenance is done by the operators for its own purposes.

Project Infield Tools for the Investigative Inspector: The project investigates tools, components and system architectures to be used by a Safeguards inspector to enhance his/her observation and "investigative" skills as well as securely retrieve local, just-in-time information while performing a complementary access inspection. Two aspects require a careful analysis: (a) the integration and the secure access to Safeguards information systems and (b) the localisation problem – the automated determination of the physical location of the inspector inside a facility such that the information to be selected and retrieved has a spatial contextual meaning. Augmented, Mixed Reality and Ambient Intelligence tools are foreseen to present the inspector with real-time documentation on devices, sites, and procedures.

Deliverables:

2007.01: Report on collaboration with IAEA, US-DoE, DG ENER on secure data transmission network (including wireless segments) for Safeguards applications – SIT-I. [DoE-EURATOM Task Sheet]

2008.01: Augmented Reality. Report on existing Augmented and Mixed Reality components and tools, and their applicability in Nuclear Safeguards

2009.01: Prototype handheld device based on ultra-portable computer and new generation 3D camera.

2011.01: Demonstration of the enhanced self-localisation system for infield inspections. Results and Report presented to IAEA Task: EC-A-01634 MSSP Umbrella Task - Support for Novel Technologies and JNT-C-01611 Application of Safeguards to Geological Repositories - ASTOR Network.

2012.01: Adapt the current prototype of the Safeguards Design and Simulation Tool into fully functional Safeguards Design VR based training tool, to be deployed at IAEA headquarters for Surveillance course training. IAEA Task: EC-B-01876 - Development of Virtual Reality Tools for Safeguards Training

2012.02: Peer reviewed paper describing the development of radiation detector simulator based on point kernel method, expand model to account for multiple sources, geometry free sources, and explore the possibility of albedo calculus in real time.

2013.01: MsThesis. Simultaneous Localisation and Mapping for Safeguards Applications.

Impact:

Information and Communication Technologies, including new sensors (such as positioning devices) have the potential in changing the way people work both in terms of efficiency and in terms of efficacy. This innovation work constitutes the R&D associated to this project. The work is organised around demonstrators bridging the gap between the potential of new devices and Safeguards problems. The R&D results for JRC's novel position localisation technique were presented to IAEA under EC-A-01634: MSSP Umbrella Task – Support for Novel Technologies. During 2013, IAEA draft the User Requirements for the Technology Evaluation

Workshop of Core Components of an Autonomous Navigation and Positioning System for Safeguards – part of IAEA's D&IS programme 2014-2015 and invited JRC to participate in the 2014 Workshop.

3.3. Major Highlight(s)

Highlight 1: Three Systems approved by IAEA for safeguards inspection use

3DLR, L2IS and LMCV laser based systems developed by NUVER have been approved by IAEA for safeguards inspection use. The 3DLR laser based system was introduced in 2003 in order to support Design Information Verification (DIV) activities in large and complex nuclear facilities (see highlight 5). The purpose of the Laser Item Identification System (L2IS) is to assist inspectors in identifying and tracking UF6 cylinders during their movements between process and storage areas at an Enrichment Plant in Japan (see highlight 2). Finally, the Laser surface Mapping System for Containment Verification (LMCV) is a portable laser range imaging system capable of authenticating/verifying the integrity of welds, a by-product of container physical sealing, with micron accuracy. The system is able of revealing penetrating attempts or substitution of containers with nuclear materials.

The 3DLR, L2IS and LMCV have successfully passed vulnerability assessments and extensive field tests. As a result 3DLR, L2IS were authorized by the IAEA for routine safeguards use in November 2012 and LMCV on April 2013.

Highlight 2: L2IS: Laser Item Identification System

Safeguarding Gas-Centrifuge Enrichment Plants – GCEP – is a challenging task, especially considering the need not to disturb 'too much' the internal plant operation. In September 2006 the IAEA concluded that a commercial technology that had been under test for the contactless identification of UF6 cylinders was not appropriate. Aware of NUVER's internal R&D work on laser-based surface mapping techniques (i.e., fingerprinting) including the associated processing and analysis software, the IAEA asked for a quick field prototype and proof of concept. In December 2006, a NUVER team travelled to a UK Enrichment plant to test the prototype. Further tests were conducted a few months later at a French Enrichment Plant. Following the positive results, during summer of 2007, NUVER designed and installed a field prototype at a Japanese Enrichment Plant. This prototype was successfully tested for about 12 months sending daily Status-of-Health reports to IAEA headquarters. The system compared the 3D surface map (micron accuracy) of an unknown UF6 cylinder with profiles stored in a database and was able to uniquely identify the current cylinder. In 2007, the system was semi-manual as the plant operator needed to position the UF6 cylinder in front of the reading system. Several reliability tests were done (e.g., surface aging, re-painting, etc.) and it was concluded that the

technique could be further developed towards a fully automated identification system. A new system was designed, developed and tested at NUVER's Ispra laboratories. The system was installed at the Japanese Enrichment plant in September 2008 and became fully operational in May 2009. The L2IS Unit 2 installed in the Rokkasho Enrichment Plant (REP) had to be switched off as per an agreement with JSGO/JNFL in early April 2013 and it is currently in this status.

Highlight 3: Commission Recommendation on NMAC QA

The European Commission, after discussions with EU member states, published in February 2009 an official Commission Recommendation for quality assurance of operators' NMAC) systems (Nuclear Material Accountancy and Control. These guidelines represent an important milestone in the ongoing dialogue between EU member states and the Commission on the objectives of audit and its role in the Euratom safeguards system. The characteristics of operator NMAC are also important for the EU/IAEA discussions regarding the application of Integrated Safeguards within the EU.

Highlight 4: Contributions to Safeguarding Geological Repositories

Many countries are looking for the final disposal of nuclear spent fuel in Geological Repositories. Since no installation has been built so far, this is a challenge to Safeguards authorities as there is the need to devise new safeguards approaches, including the characterisation of the fuel, the assurance that all fuel remains stored (i.e., not diverted) and the assurance that the fuel is kept securely stored for hundreds of years. This poses the problem of ensuring that the tunnels have been built according to plans and there are no secondary galleries or accesses. All this verification needs to be done during the construction phase as well as prior to the repository closure. NUVER undertook collaboration with the Finnish regulatory authority STUK and in Summer 2007 a 3D scan of the whole length of the tunnel at that time – 2.2 km – was created in two days. The scan has millimetre accuracy and was the basis for a technical exercise with STUK and the site operator to compare methodologies, equipment, processing software, etc. In 2008, these results were reported to the IAEA ASTOR Network of experts for Safeguarding Geological Repositories. Viewing the quality and relevance of the results for Safeguards, the IAEA and DG ENER further investigated the use of laser scanning to accurately characterise the tunnels in a repository as well as detecting changes. The approach was adopted in 2013 by IAEA and DG ENER for the Design Information/Basic Technical Characteristics Verification (DIV/BTC) of ONKALO Geological Repository (W0LF) in Finland.

Highlight 5: 3D Laser based Design Information Verification

There is an increasing and significant need for enhanced methods for verifying plant design information (DIV) as nuclear fuel cycle facilities are growing in size, complexity, and flexibility. In 2002, as part of the European Commission Support Programme to the IAEA, NUVER proposed a laboratory prototype of a laser based system to assist the verification of the Rokkasho Reprocessing Plant. Following positive results the system was adopted in 2013 by IAEA and was extensively used since then. Today, NUVER's DIV related developments are a reference worldwide.

Applications include the verification of effectiveness of legislation - EURATOM Treaty Safeguards, use during Physical Inventory Verification (PIV) / Basic Technical Characteristics (BTC) Verification at EU fabrication and reprocessing plants. Trials were also conducted in US-DoE gas enrichment and in ABACC (South American Regional Safeguards Agency) facilities.

Highlight 6: Information Integration tools

Following R&D and demonstrators during the 6th Framework Programme, DG ENER requested the JRC to assist in building an operational system (installed in their secure network) capable of accessing their different internal Safeguards databases in a unified way, with a single point of access. This system is operational since 2008. Targeted R&D continued with the LIMES project with new concepts for integrating information, focused on the needs of the non-proliferation image analyst. The platform has been installed for evaluation at the European Satellite Centre (EUSC) and the results have been disseminated in various publications. The integration platform has been used and further improved during the follow-up projects G-MOSAIC and G-SEXTANT and influenced the design of equivalent systems at EUSC and IAEA. The Geospatial Exploration System (GES) at IAEA uses similar concepts to provide the safeguards analyst with spatial and non-spatial information related to a nuclear facility.

Highlight 7: Safeguards Review Station

A first demonstrator – VideoZoom was installed at DG ENER image review in November 2011. ENER inspectors participated in the pre-evaluation of the demonstrator with positive results. A full evaluation both by DG ENER and IAEA's inspectors took place in Q1 2012 with extremely good feedback from end-users on the new paradigm for the review of surveillance images. This originated a new EC-SP task for the IAEA – started in 2014 - EC-E-01992 Research, Development and Evaluation of a Surveillance Review Software based on Automatic Image Summaries (VideoZoom). In 2013 VideoZoom project was selected for funding under JRC's Proof of Concept instrument as an innovative technology.

4. Further Information

4.1. Integration and Networking

4.1.1 Collaborative activities of NUVER within the JRC.

- Collaboration with the three actions (AMENUS/IANUS, PHYMOD/NUSIM and NUMAMET) inside IPSC/ITU's Nuclear Security Unit
- Collaboration with IPSC – ELSA Unit within the framework of the RAILPROTECT "Innovative Technologies for Safer and More Secure Land Mass Transport Infrastructures under Terrorist Attacks" project, financed by DG ENER focusing on the assessment of the structural vulnerability of specific construction types encountered in the rail transport. NUVER provided accurate 3D scans for a Paris train station and subway coach, upon which the structural models were created.
- Collaboration with IES-SOLO Action: two open fields of collaboration (a) investigation on the use of Earth Observation tools for nuclear non-proliferation studies and (b)

support to the creation of accurate 3D models of specific ecosystems for the evaluation of remote sensing products

- Collaboration with IES-Climate Change Unit, Action 24002 [GHG-AFOLU - Greenhouse Gases in Agriculture, Forestry and Other Land Uses] for 3D Modelling of trees for faster and accurate forest models in view of carbon exchange studies.

4.1.2 Networking and Collaborative activities of NUVER with external bodies.

Below a list of the NUVER collaborations with external bodies:

European Commission: DG ENER: list of active tasks

- SRS: Safeguards Review Station – R&D tools for image reviews
- 3D-LVS: 3D Laser-based Verification System (AA-3DLVS)
- 3D-OCR: 3D Laser based OCR (AA-3DLVS)
- 3D-LVSG: SPRS - Laser based verification of the integrity of ventilation stacks grids (AA-3DLVS)
- LaSSy2: Laser Surveillance System – La Hague (AA-LASSY)
- Support to Encapsulation Plants/Geological Repositories (BTC/DIV) (AA-3DLVS)

Finished tasks

- SIT-ES: Site Information Tool – Euratom Safeguards
- Connection IAEA approved Surveillance Camera to ENER RADAR – Nucleonics Data Acquisition and Analysis Software package

IAEA: European Commission Support Programme tasks involving NUVER:

EC-E-01549: 3D Laser Surface Mapping of Canister Closure Welds

EC-E-01636: Software Engineering Support for 3D Camera Development

EC-E-01696: L2IS: Laser Item Identification System

EC-E-01425: 3D Laser Range Finder for Design Verification in RRP.

JNT-D-01657: Signatures of Nuclear Fuel Cycle Related Processes

EC-D-01664: Software-Hardware and Database Provision for Satellite Imagery

EC-D-01723: Use of Satellite Imagery Data for Geological Repositories Monitoring

EC-A-01634: MSSP Umbrella Task – Support for Novel Technologies

JNT-C-01611: Application of Safeguards to Geological Repositories - ASTOR Network

EC-B-01844: Training of Safeguards Inspectors 3DLR (3D Laser Range Finder).

EC-E-01830: Vulnerability Assessment of the Next Generation Surveillance System (NGSS)

CEA – JRC Action Sheet:

3D Technologies for Security Emergency Response

ABACC – EURATOM Action Sheets:

AS 1-01: Training - ABACC Participation in JRC-IAEA Course on Using 3D Laser Scanning System for Design Information Verification

AS 1-02: JRC Seminar on 3D Range Finder (3DLR) for Design Information Verification

Informal Collaborations:

STUK (Finland): Collaboration concerning the acquisition, processing, management and analysis of 3D models for Onkalo tunnels – results reported to IAEA ASTOR Network

IRSN (France): Dedicated Training Course on Statistical Methods for Nuclear Material Balance Evaluation

MEPhI (Russia): Training Course on Statistical Methods for Nuclear Safeguards (part of MEPhI's Master of Science in Nuclear Material Accountancy and Control and Physical Protection)

DOE – EURATOM Action Sheets:

Action Sheets

AS-30: 3D Sensing Technologies for Unattended Monitoring (Sandia Labs)

AS-32: Enhanced Data Authenticity via an Electronics Platform for the Secure Transmission and Recording of Sensors (Sandia Labs, DG ENER)

AS-35: Investigation of Combined Measurements with Three Dimensional Design Information Verification System, Gamma-Ray and Neutron Imaging Systems for International Safeguards Applications (ORNL, LLNL, LBL, ABACC)

AS-20: Wireless Data Collection and Secure Transmission (Sandia Labs, DG ENER)

AS-27: Investigation of Applications for the 3D DIV System at DOE Facilities in the United States (ORNL)

4.2 List of Competitive Activities

A list and short description of the competitive activities linked to the action (2007 to mid-2009)

- **EURITRACK:** an FP6 project aiming at the detection of illicit trafficking or inadvertent movement of nuclear materials or radioactive sources and chemical warfare agents in airports and seaports. NUVER was responsible for the "Information System" Work package integrating (a) Data acquisition for all available information sources (XRS, TNIS, E-seals); (b) Decision-making aid to the operator for data interpretation; (c) the interfaces to other container management software and (d) Database management
- **Eritr@C:** This project sponsored directly by DG-JLS extends EURITRACK. NUVER will be continuing the work developed under EURITRACK
- **LIMES**: an FP6 Integrated Project aiming at the development of *satellite-based services providing relevant information and decision-support tools* to the following

application domains: (a) Surveillance of the EU borders (land and sea); (b) Organization of humanitarian relief and reconstruction; (c) Surveillance and protection of maritime transport and (d) Protection against emerging security threats. Within the latter domain, NUVER leads a work Package on Treaty Monitoring providing an integrated framework and platform to supporting the Non-Proliferation image analyst. The focus is on the integration of data and documents from multiple sources.

- **G-MOSAIC:** (GMES Services for Management of Operations, Situation Awareness and Intelligence for Regional Crisis) is a GMES – Global Monitoring for Environment and Security – Pilot Project under FP7. The project aims at identifying and developing pilot services for the provision of geo-spatial information supporting EU external relations policies directed to maintain a peaceful global society. G-MOSAIC is structured in two thematic clusters: WP2000 (Support Intelligence and Early Warning) and WP3000 (Support Crisis Management Operations) as well as five supporting horizontal clusters. NUVER contributes to WP2200 (Non-Proliferation and Treaties) by providing and customizing an integrated information management platform for the demonstration case on "Continuous surveillance of nuclear facility"
- **G-SEXTANT** (Service Provision of Geospatial Intelligence in EU External Action), mainly for the work package dedicated to treaty monitoring and non-proliferation (WP 550). NUVER role is to i) contribute to the user coordination and scenario requirement for WP550 and ii) adapt, deploy and populate its information integration platform dedicated to the geo-spatial non-proliferation analyst.
- **IMSK:** Integrated Mobile Security Kit - is an FP7 Security Research Integrated Project aiming at combining technologies for area surveillance, checkpoint control, CBRNE detection and support for VIP protection into a rapid deployment mobile enhanced security system. NUVER's main role is integrating its own 3D modelling technologies within a security application environment.
- **RAILPROTECT:** "Innovative Technologies for Safer and More Secure Land Mass Transport Infrastructures under Terrorist Attacks" – the participation was done via IPSC-ELSA-PVACS Action
- **SOFAR:** This full-cost third party work project follows a collaboration R&D agreement with the Italian pharmaceutical company Sofar for the development of a tele-surgical robotic system applied to minimally invasive surgery. A prototype system has been developed and is being used for clinical trials prior to commercialisation. The system is based on NUVER's previous internal R&D results protected by patents and copyright agreements.
- **TACIS – Andreeva Bay:** This project aims at the safe retrieval of spent fuel assemblies from the Andreeva Bay storage site, Northwest Russia. JRC developed a 1:1 scale mock-up of a storage cell to assess the performance of a dedicated toolset. Further, JRC identified an efficient procedure to retrieve the spent fuel.
- **TACIS – Snezhinsk:** This project aimed at installing a robotic system for the automated inventory of Plutonium inside a storage area. A new project includes the training component guaranteeing the sustainability of URSiMTC – Ural Siberian Methodology and Training Centre

- **TACIS – Kursk & Kalinin:** This project aims at updating the NMAC – Nuclear Material Accountancy and Control – system at the Kursk and Kalinin Nuclear Power Plants.
- **3D Reconstructor**: In 2003 JRC signed the first commercialisation licensing agreement for the 3D Reconstructor™ developed in NUVER. In 2008, this agreement was modified and included the access to the source code and the authorisation to modify it for specific markets. The 6 years Contract with Gexcel 2008-2013 has generated 500 K€ of royalties for the JRC. In December 2013 there were about 600 licenses/300 clients of the JRC 3D Reconstructor software distributed all over the world. Market Sales in 2013 415 K€.

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 – 2013

Action *53106 – NUMAMET*
Nuclear Materials Measurements Techniques
Action Leader: *Reinhard BERNDT, E.08*

Authorising Officers: *Willem Janssens, E08-Nuclear Security*
Leading Institutes: *Institute for Transuranium Elements (from 01.01.2011 onwards)*

0. Policy Area

FP7 Policy Theme	5 The EURATOM programme
Agenda No & Title	5.3 Nuclear security
Sub-Agenda No & Title	5.3.1 Nuclear Safeguards, Additional Protocol and Combating Illicit Trafficking

1. Rationale of the Action:

Nuclear measurement techniques are essential tools for activities such as nuclear safeguards, non-proliferation issues, and nuclear security. The evolution of nuclear safeguards and the implementation of the Additional Protocol have brought about new and challenging Non Destructive Assay (NDA) tasks and more varied safeguards inspection regimes. These changes require better plant integration of measurement stations and improved integral analysis of data from combined measurement stations and remote monitoring. New NDA equipment of higher quality and sensitivity needs to be qualified and validated before taken into operation, and also training in the use of new equipment and new analysis methods needs to be provided to the nuclear inspector. To support these aims the JRC provides the expertise in NDA methods and equipment, nuclear fuel cycle competences as well as the necessary nuclear materials and experimental facilities. Clearly, all these methods and approaches apply in the same way to nuclear security.

This Action has contributed to the strengthening of ENER (EURATOM) and IAEA inspectorates by developing and/or upgrading of NDA equipment used in field, by providing direct support with inspections, and all this continuously accompanied by general and appropriate special inspector training; moreover with contributions to the JRC education activities for students. The research part of the Action is searching for and published on new techniques with active interrogation (PUNITA) in preparation of potential application cases with nuclear security.

2. History and development of the Action:

The action was created in 2006 and when a very large action comprising the whole Nuclear Safeguards Unit was split into four actions. It has kept its profile since then.

3. Description of the Action

3.1. Clients and Stakeholders

Main clients, collaborators, and research partners:

- ENER (EURATOM)
- IAEA
- DG HOME
- DG DEVCO
- Fraunhofer-Institut Euskirchen (Germany)
- CEA Cadarache (France)
- CEA DAM Saclay (France)
- NRCN (Israel)
- Politecnico di Milano (Italy)

- Umeaa (Sweden)
- LANL (USA)
- ORNL (USA)
- STUK Helsinki (Finland)
- BUTE Budapest (Hungary)
- Swedish Defence Research Agency, Umeå (Sweden)

3.2. Major Objectives, deliverables and impacts

The following gives only a short general view:

Objective 1: R&D in the field of nuclear safeguards / nuclear security for the main clients ENER and IAEA

Deliverables

Typical deliverables are scientific peer reviewed journal articles and contributions to conferences and meetings on new research results as well as technical reports and notes concerning practical aspects mainly of support tasks.

Apart from the examples mentioned for PUNITA (objective 2) and as direct support to EURATOM and IAEA (objective 4), there are research activities which aiming at new methods for later application in the field of nuclear safeguards and security. Examples are

- Pilot project Gamma tomography, common project of IAEA, BUTE (Hungary), STUK (Fi) and JRC, Ispra.
  Aim: Provide an instrument for verifying the completeness of nuclear spent fuel during their transfer into a final repository.
- Test of the MCA-527 for gamma spectrometry and its arrangement for neutron counting,
  Aim: Demonstrate that the new instrument fulfils the requirements of EURATOM and IAEA.
- A study for the IAEA "Survey of State of the Are NDA methods Applicable to UF6 Cylinders
  Aim: Identify an applicable method which allows "looking" into the huge UF6 cylinders (up to now, the central part of the cylinders is invisible for inspectors).
- Enrichment measurements with $LaBr_3$ detectors
  Aim: Description of the potential use of the new room temperature gamma radiation detector with nuclear safeguards.
- Modelling of gamma spectra of Ge detectors
  Aim: Replace experimental calibration by numerical calibration (as possible for some neutron counters).
- Experimental Determination of the Self-Absorption Factor for MTR plates,

Aim: Find a method which allows routine measurement of all types of MTR plates without complicated and unreliable individual experimental determination of the self-absorption.

- Experimental study of different types of ^{10}B neutron counter tubes as alternative for ^{3}He for nuclear safeguards applications.
  Aim: Replace ^{3}He counters for high efficiency counters for nuclear safeguards with a large ^{3}He inventory.

In addition to the own work in the PERLA laboratory at Ispra, the laboratory itself has become a "user laboratory" for external stakeholders for their work during FW7, both for common work and for workshops.

Impacts

The impact of the above mentioned examples lies mainly in research results which allow now application of some solutions. Several of the above research tasks were followed or are still being followed in current work with the aim of practical implementation:

- The successful tomography tests at Ispra and later at other places will lead to the set-up of such a device for partial defect test at the world's first final repository for spent nuclear fuel in Finland, the work is ongoing.
- The MCA-527 is about to be one of the key instruments for gamma spectrometry with EURATOM and IAEA, and - due to the contributions of this action - also for neutron counting.
- The proposed solution for measuring the ^{235}U mass in UF_6 cylinders is now followed by IAEA and EURATOM with experimental work.
- $LaBr_3$ detectors are a very good alternative for NaI and CZT detectors (but still very expensive).
- A modelling tool for Ge detectors is available and can be used for estimating the detector response in inspection places which are complicated to access (but cannot replace experimental calibration work).
- A new method for safeguards on MTR plates will be implemented in 2015 into routine use by EURATOM using the new method for the determination of the self-absorption.
- Basing on the experimental results with ^{10}B neutron counter tubes, design work has shown that an applicable neutron counter can be provided with sufficiently good efficiency for safeguards applications.

PERLA as "external user laboratory" was hosting measurement campaigns on nuclear material of several external entities for their purposes in the field of nuclear safeguards and security, either as a common work, or their sole task, or as small workshops. Examples of this action NUMAMET are:

- Security instrument tests with Fraunhofer Euskirchen ("Deytective versus Falcon", "Fission meter versus slab counter",
- Gamma spectrometry measurements on Pu and MOX with the Swedish Defence Research Agency,
- Multiplicity neutron counting tests with NRCN, Israel,

- Test of a gamma camera of CEA DAM Saclay (now commercialised),
- Gamma and neutron measurement tests with GBS for MCA527.

Further activities as "external user laboratory" were organised by the action NUSIM (no. 53201), e.g. with the University of Michigan, in the Scintilla project of for collaboration with a spin-off project of the ETH Zürich for ^{3}He replacement.

Objective 2: Start of the research work in the experimental facility PUNITA, a Pulsed Neutron Interrogation Test Assembly, in 2008.

Deliverables

The operation of the PUNITA laboratory represents a large step forward to the work with new techniques for active neutron counting. It permits basic investigation for the detection of small amounts of fissile material and has the potential to detect / identify other threat or fraud material. Typical deliveries are scientific results describing the potential of the pulsed neutron measurement technique in combination with fast detection systems for the analysis of the response of the material under investigation.

Impacts

The purpose of PUNITA, including the infrastructures of the Neutron Laboratory, is to conduct experimental research in non-destructive assay (NDA) methods and instrumentation for applications in nuclear security and nuclear safeguards.

The strength of the facility is the possibility to compare computer models with experiments verifications on optimized instrument configurations, and to use the tested models to estimate performance values of scaled-up industrial size facilities.

- The safeguards project on PUNITA concerns the mass determination of small quantities of fissile materials through active neutron interrogation. The activities on this project included: characterization of the interrogating neutron flux, calibration of detection systems on the facility, development of a list mode neutron analyser for active measurements (Multi Channel Frequency Analyser, MCFA), experimental evaluation of a compact device for fissile samples below milligram fissile mass, and progress on the interpretation model for active neutron assay.

  One paper example is: “A novel method for active fissile mass estimation with a pulsed neutron source” Dub et. al. NIM-A, 715 (2013) 62-69.

- The nuclear security project on PUNITA concentrated on the investigation of methods for detection of special nuclear materials. This includes experimental studies of detection of fission signatures such as prompt and delayed neutrons and gamma rays. A particularly promising signature is the coincident prompt fission neutrons which can be detected in a multiple detector arrangement using very short coincidence gates. Results are published both at conferences and in journals including simulated performance values for a potential facility intended for air cargo containers.

One paper example is: “SNM detection by means of thermal neutron interrogation and a liquid scintillation detector” Ocherashvili et. al. (2012) JINST 7 C03037.

- The PUNITA facility as a research tool, licensed by the Italian state, easily attracts interest from external collaborators. The main collaborators on the two application projects mentioned above were:
  - Fraunhofer-Institut (Euskirchen) on neutron spectrum measurements in PUNITA.
  - CEA Cadarache on the development of methods for SNM detection.
  - NRCN Israel for both methods of fissile mass determination, and coincidence methods for SNM detection.

Objective 3: Nuclear inspector training.

Deliverables

The action members perform every year in the order of five to eight inspector training courses of one week duration in the nuclear laboratory PERLA, they are held for EURATOM and IAEA inspectors but also from national authorities, e.g. from Spain, South Africa or Japan. The schedule is at http://nuclearsafeguards.jrc.it/web_inspector_training/01-index.htm. In FW7 (2007-2013), the following courses were performed:

Course title	no. of courses
Regular courses	
U enrichment verification with gamma spectrometry (one week)	11
U enrichment with gamma spec. - MGAU module (two days)	3
Pu isotopic verification with gamma spectrometry (one week)	8
Passive neutron assay (one week)	10
RADAR / CRISP (one week)	4
Special courses	
Waste drum monitor (three days)	2
Advanced NDA (for IAEA, 2 weeks)	1
Pu diversion detection (for IAEA, one week)	1
In-field course U enrichment (one week, Pierrelatte)	1
Test and in-field training for new safeguards instruments (1 week, Lingen)	1
Decommissioning summer school (one week)	1
Contribution to the ESARDA education course	7

Impacts

The impact of the inspector training of the Action has an important impact. Actually, the Action is the main provider of this inspector training for ENER. It is essential for nuclear material inspectors to have the occasion to have training with real nuclear material in a nuclear laboratory. Many years of experience show that the trainees profit from the laboratory courses with real nuclear material and real instruments. This holds for all trainees, rather independent on their profession (physicist ... engineer ... layer, or technician ... scientist). There

is no other laboratory in Europe where both qualified staff and the required infrastructure exists. The courses are well appreciated by ENER and the IAEA training section, which profit a lot from our training support.

Objective 4: Direct support to ENER and IAEA.

Deliverables

The action NUMAMET has delivered major support to DG ENER and IAEA, e.g.

- AA Gamma Upgrade La Hague (for ENER):
  Aim: Install a protected measurement system in a place where "normal" equipment does not work,
- Arrange for automatic passive neutron counting at Melox
  Aim: Replace inspector work by automatic solution.
- JRC Waste Drum Monitor Upgrade (for ENER):
  Aim: Upgrade the instrument for multiplicity counting, e.g. increase the efficiency, lower the detection limit and allow measurements on inhomogeneous matrices.
- Feasibility study "State of art of NDA methods applicable to UF6 cylinders" (for IAEA)
  Aim: see objective 1
- Participation of specialists in several Primary Inventory Verifications (PIV) at Melox and CERCA (both in France).
  Aim: Deliver specialist support to the inspection work of EURATOM.

Impacts

The support is directly related to the inspection work of ENER and IAEA. It concerns scientific / technical work on major, special inspection tools or methods (not the inspection work itself - except for support with the PIVs). Provided solutions are available for direct use of ENER for inspection work, e.g.

- The upgraded installation is running reliably at La Hague (UP3), the same solution shall be extended to another place at La Hague and - maybe - at Melox.
- The passive neutron counting with a CNR counter in Melox is running automatically,
- The upgraded waste drum monitor for small masses of Pu in heterogeneous matrices is ready for its application by EURATOM, the inspectors are trained, EURATOM has to define the place of application.

3.3. Major Highlight(s)

R&D highlights:

- The large experimental facility PUNITA started its operation in 2008. The beginning of the scientific work resulted already in the first publications. PUNITA is becoming an attractive facility for outside researchers. It attracted external research partners like NRCN Israel and CEA and direct collaborations with them became dominating. Important is the orientation: Research for nuclear material detection for nuclear security.

- The technical functioning of the spent fuel tomography (IAEA project) was demonstrated for the first time in a spent fuel pond in Ispra, with real spent fuel, and later it was shown that the method can be applied for real spent fuel of standard types. This is an important scientific / technical step with the preparation of the operation of the Finnish final repository for spent nuclear fuel.

Training highlights: Two new inspector training courses of high level

- In spring 2008, the "Advanced NDA Course for Nuclear Material Inspectors" was held for the first time in PERLA, for IAEA. This 2 week course, only for experienced inspectors, integrates all standard gamma and neutron measurement methods and provides like this the possibility to do training for complete declarations.
- In autumn 2008, the first Common IAEA-EURATOM course "Pu Diversion Detection" was held in PERLA. Also this was a course for experienced inspectors, they had to work in groups and a whole inventory of nuclear material had to be verified.

4. Further Information

4.1. Integration and Networking

The action is well embedded in internal collaborations (with IPSC, G06, e.g.) and has external collaborations esp. with specialists from the IAEA and in the various levels of information / cooperation within ESARDA.

4.2 List of Competitive Activities

- AA Gamma Upgrade La Hague (for ENER)
- AA Upgrade UP2
- JRC Waste Drum Monitor Upgrade (for ENER)
- AA on 235U Mass Determination in HEU in MTR Plates

4.3. Mobility and training of researchers

Contacts are made to invite a specialist in the field of neutron counting as visiting scientist to PUNITA. The collaboration with NRCN Israel has been and continues to be outstanding.

There were external experts present in the lab, from Germany, IAEA, Israel, Italy as well as post doc students and trainees from different countries. A former colleague left for LANL and we expect to profit from this contact in future (esp. concerning collaboration in the field of fast nuclear electronics).

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE

Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action *53108 NTAS*
Nuclear and Trace Analysis for Safeguards
Action Leader: *Magnus Hedberg, E07*

Authorising Officer: *Klaus Luetzenkirchen, E07*
Leading Institute: *Institute for Transuranium Elements*

0. Policy Area

Policy: 5. Euratom Programme,

Agenda 5.3. Nuclear Security,

Sub-agenda 5.3.1 Nuclear Safeguards, Additional Protocol and Combating Illicit Trafficking

1. Rationale of the Action:

The Euratom Treaty entrusts the Euratom Community with responsibility for ensuring that ore, source materials and special fissile materials are used for the civilian purposes for which the materials have been declared. Such monitoring also concerns compliance with Euratom supply rules and all Community control commitments towards third countries or an international organisation. Since 1958, the Commission has assumed full responsibility for exercising such safeguards at European level. Worldwide, IAEA independently verifies the correctness (Non-Proliferation Treaty) and the completeness (Additional Protocol) of the declarations made by States about their nuclear material and activities for the prevention of further spread of nuclear weapon technology. The NTAS action assists the Commission with its responsibilities, particularly the safeguarding of the peaceful use of nuclear materials, and international cooperation for nuclear safeguards and security and support for the IAEA, respectively. It contributes to the Commission's international action in the field of research. .

The NTAS action contributed to the nuclear material accountancy measures of DG-ENER and the IAEA by providing advanced analytical measurements, operation of Euratom On-Site Laboratories at two reprocessing plants and varied technical support. The action provides continuous R&D and technical innovations to implement the evolving safeguards policy of present and future fuel cycles both for DG-ENER and for the IAEA. The action worked at establishing increased measures to detect undeclared activities and materials using the techniques of High Performance Trace Analysis (HPTA), also called environmental sample analysis.

2. History and development of the Action:

The action was created in the beginning of 2007 when the previous action "Safeguards Research and Development" was split into the two actions "Forensics Analysis and Combating Illicit trafficking" and "Nuclear and Trace Analysis for Safeguards". This improved the focus on the two topics described in the actions and enhanced the visibility in these two important areas for nuclear safeguards and security.

3. Description of the Action

The Action provided analytical services both to DG-ENER and IAEA on nuclear sample analysis at the laboratories of ITU, at the On-Site Laboratories of La Hague and Sellafield and through in-field analyses at European LEU fuel fabrication plants. The action provided environmental sample analysis using SIMS and LG-SIMS mass spectrometers. The environmental sample analyses were made for both IAEA and DG-ENER for verification of declared nuclear activities and of the absence of non-declared nuclear activities. In addition, special samples were analysed for IAEA with non-routine analytical requirements. The total amount of sample analyses amounted to 1200-1500 per year. The action provided direct support to the IAEA in the

establishment of an On Site Laboratory (OSL) at the Rokkasho reprocessing plant (Japan). Another important task for the action NTAS was to strengthen the current Safeguards regime both in Europe and internationally by its R&D efforts for improvements in the methods of trace particle analysis and measurement techniques for nuclear accountancy purposes. The action played a major role in implementing LG-SIMS both at JRC/ITU and at IAEA. A substantial part of the action's work was made in the form of competitive activities with Commission services and third parties, regulated, e.g., under Administrative Arrangements (AA). The action complemented other actions in nuclear safeguards and security. The Action provided a broad field of analytical measurements in support to other nuclear safety and security Actions of the JRC.

3.1. Clients and Stakeholders

Customer/users (outside the European Commission):

- Sellafield Ltd
- Areva NC
- EU Member State competent authorities
- International Atomic Energy Agency (IAEA)
- Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC)
- The Korea Institute of Nuclear Non-proliferation and Control (KINAC)

Customer DGs (inside the European Commission):

- Joint Research Centre – IRMM
- Joint Research Centre - ITU
- DG Energy (DG-ENER)

3.2. Major Objectives, deliverables and impacts

Objective 1: Support DG-ENER activities by providing required analytical services on nuclear material measurements and on trace particle analysis. An analytical capacity of up to 200 nuclear samples/year should be available for DG-ENER as required. HPTA samples should be analysed as required with a capacity of at least 50 samples/year. Inspection materials for HPTA samples should be produced as required and should be delivered to DG-ENER.

Deliverables

- Analytical results and provided materials (sample kits)
- Training on Safeguards-relevant techniques.

Impacts

The delivered analytical data and supplied inspection materials are necessary for making safeguards conclusions on European nuclear installations.

Objective 2 Support IAEA safeguards activities by providing required analytical services on nuclear material measurements and on trace particle analysis with a capacity of 100 samples/year made available. Provide training of inspectors and

analysts as required. Support the IAEA in its work in operating an onsite laboratory at Rokkasho reprocessing plant.

Deliverables

- Analytical reports of the results obtained.
- Training to IAEA's inspectors and analysts
- EC support program to IAEA: Task reports

Impacts

The action is member of the IAEA's Network of Analytical Laboratories (NWAL). It is the only external supplier of safeguards nuclear material analysis to the IAEA. The Action continuously provides analytical results on nuclear inspections samples for the control of physical inventories at nuclear facilities and environmental samples in the search for non-declared nuclear material handling. The action is also continuously involved in training inspector analysts for work at the Rokkasho reprocessing plant. This reprocessing plant is one of the largest single Safeguards tasks that the IAEA has today with its designed throughput of 800t of spent fuel per year recovering annually 8t of plutonium.

Objective 3 Support DG-ENER through operation of the two On-Site Laboratories at the reprocessing plants of La Hague and Sellafield. This objective is a long-term commitment that provides DG-ENER with the operation of the laboratories resulting in more than 250 mission weeks and more than 700 nuclear sample analyses/year. Work is also performed under this objective for a continuous modernisation of the laboratories' infrastructure and equipment as well as implementing improvements in the analytical methods.

Deliverables

- Periodic reports of the work performed in managing and operating the two On-Site Laboratories; refurbishment of laboratories.
- Analytical reports of the results obtained.

Impacts

The operation of the On-Site Laboratories plays a key role for DG-ENER in its Safeguards work of the two reprocessing plants.

Objective 4 Provide in-field analytical support (COMPUCEA instrumentation) to DG-ENER and IAEA at European Low Enriched Uranium fuel fabrication plants. Assist IAEA in using the Compucea analytical method (developed at ITU/JRC) outside the EU. Provide training of IAEA staff for this in-field analytical work.

Deliverables

- Annual reports on the analyses performed at the fuel fabrication plants.
- Training of IAEA staff for Compucea analytical work

Impacts

The delivered analyses provide necessary data for DG-ENER and IAEA in their Safeguards conclusions for the European fuel fabrication plants. The work in providing the Compucea method for IAEA will also strengthen the international Safeguards efforts.

Objective 5 Perform research in nuclear and trace analysis methods in support of the work tasks for DG-ENER and IAEA. Give R&D support within the EC support program to the IAEA as required.

Deliverables

- Publications on new and improved methods to achieve European and international Safeguards objectives.
- IAEA support program reports
- New improved methods

Impacts

The performed R&D work is continuously improving the abilities for European and international safeguards efforts both for verification of nuclear material accountancy and in the search for non-declared nuclear activities.

3.3. Major Highlight(s)

Continuous technical innovations and research at ITU is required to implement the evolving safeguards policy of present and future fuel cycles both for DG-ENER and for the IAEA. Below are several highlights in the recent efforts made within the action.

3.3.1. Improvements in NDA techniques for analysis of nuclear materials.

- **Monte Carlo Modelling for Extended Capabilities of the Hybrid K-Edge/K-XRF Analysis of Uranium and Plutonium Solutions.** The Hybrid K-Edge/K-XRF Densitometry (HKED) has become a highly accurate and reliable method for U and Pu analysis. It is routinely used for nuclear material accountancy and process control at the large-scale nuclear reprocessing facilities worldwide. Through the combination of the K-edge transmission and KX-ray fluorescence (XRF) techniques, the method is capable of measuring the concentration of U and Pu in solutions with a combined relative standard uncertainty of < 1% at concentration levels above 0.5 g/l. The new development consists of a Monte Carlo modelling with the aim of reducing the need for lengthy calibrations currently necessary to ensure accurate XRF measurements. In addition the modelling can be used to allow for an extension of the applicability of the HKED method to non-standard U/Pu mixtures and sample matrices without investing a great deal of extra calibration work.

- **Finalising development and implementation of the second generation Compucea method.** The Combined Product Uranium Concentration and Enrichment Assay (COMPUCEA) technique is deployed for in-field physical inventory verifications (PIV) carried out annually at European fuel fabrication plants. Joint inspections by DG ENER and IAEA analysts of ITU measure the uranium concentration and enrichment in uranium fuel pellets. A new portable instrumentation has been developed and has been successfully implemented for the physical inventory work at fuel fabrication plants. It is based on the measurement of uranium concentration by L-Edge densitometry (rather than the previous K-Edge approach) and of uranium isotope ratios by gamma spectrometry. Compucea was accepted by IAEA as class A equipment and transferred to the IAEA for inspection use outside Europe. Assistance has also been given to the IAEA in field trials and in relevant inspector training.

- **Development of a new HKED Instrument for the Mayak Reprocessing Plant RT-1 for Conventional and Fast Breeder Fuel.** The project "Modernisation and Enhancement of Nuclear Material Accounting and Control (NMAC) of the Mayak RT-1 Plant" in the Russian Federation is an undertaking funded by the TACIS programme of the European Union. This includes an upgrade in the form of dedicated process instrumentation, analytical equipment, hardware and software tools for near-real-time accountancy. For the improvement of radiated fuel analysis in process solutions the implementation of a Hybrid K-Edge Densitometer (HKED) is part of the project. The design, manufacturing and tests of the instrument were technically managed and supervised by the Joint Research Centre (JRC) of the European Commission in close cooperation with the partners of the Russian Federation.

- **Non-destructive measurement of the plutonium content of high-active liquid waste**. To verify that all Pu in a reprocessing plant is accounted for, IAEA inspectors need a method for measuring Pu in high-active liquid waste (HALW) remaining after reprocessing of spent fuel. HALW contains fission products, cladding material, traces of U and Pu, and undissolved residues. Some of the Pu in HALW is attached to the residues. However, constraints at an IAEA on-site laboratory do not allow use of common destructive methods to measure Pu in the residues. Therefore, ITU is developing a non-destructive method to measure the total Pu content of HALW. The method is based on X-ray fluorescence measurements combined with stirring the HALW. Tests with known amounts of Uranium in simulated HALW were done in ITU using a miniature stirrer installed into a modified sample changer.

- **Measurement of the Pu concentration of European MOX pellets by neutron coincidence counting (NCC)**. A neutron-coincidence counter was calibrated for the non-destructive measurement of Pu concentration of mixed oxide (MOX) fuel pellets produced in Europe. The aim was to implement a non-destructive procedure for verifying the declared Pu inventory which can be used by safeguards inspectors in field. A set of MOX pellets was used to calibrate and to check the performance of the method. After NCC and gamma counting, the pellets were characterized by destructive methods. The bias between Pu concentrations obtained from NCC and from isotope-dilution mass-spectrometry was found to be 1 to 3 % depending on the calibration curve and on the source of isotopic data used for calculation. This accuracy may serve for a preliminary assessment of the Pu inventory in MOX pellets to spot possible Pu diversion. However, for material balance evaluation purposes the smaller uncertainties associated with destructive assay remain preferable.

3.3.2. Improved particle analysis by Large Geometry – Secondary Ion Mass Spectrometry (LG-SIMS) for Safeguards purposes.

When uranium is processed in industrial quantities, it is very difficult to avoid the release to the immediate environment of micron to submicron-sized aerosol particles containing the isotopic signature of the handled materials. This allows nuclear safeguards authorities to monitor the nuclear materials handled at nuclear facilities. Until recently, particle analyses have predominantly been performed using the small geometry CAMECA IMS 3F-7F instrument series. The performance of these instruments is however often limited by the occurrence of isobaric interferences, in

particular for the minor isotopes (^{234}U, ^{236}U), that often could not be resolved without compromising the transmission of the instrument, resulting in lower sensitivity.

A recent breakthrough to solve this problem has been the implementation of Large Geometry - SIMS. A fully equipped LG-SIMS laboratory for safeguards purposes was established through a joint project between DG-ENER and JRC-ITU. The newly constructed laboratory was inaugurated in June 2012. The project of optimising and benchmarking the LG-SIMS instrument for safeguards purposes was made in collaboration with the manufacturer CAMECA (Paris, France), the NORDSIM laboratory (Stockholm, Sweden) and the University of Western Australia (Perth, Australia). A thesis made at ITU/JRC within this action was a large part of the report to the IAEA on the task EC A 01777 ”Evaluation of Ultra-High Sensitivity Secondary Ion Mass Spectrometry for Environmental Samples”.

In short, the LG-SIMS today provides isotopic data on particles that are state-of-the-art and in a timely way. The latter is important for the safeguards application, where timely analysis can be critical, especially in facilities with a high throughput. Today several IAEA network laboratories (NWAL) have implemented this technique for safeguards purposes which is a major breakthrough for strengthened safeguards. Today the following NWAL laboratories have LG-SIMS facilities: IAEA/ESL, ITU/JRC, the Atomic Weapon Establishment (AWE) in the UK, the Laboratory for Micro Analysis (LMA) in Russia and the University of Western Australia (UWA).

3.3.3. Combination of Scanning Electron Microscopy and Secondary Ion Mass spectrometry.

As result of a safeguards related request, a programme was started to search for uranium particles in soil samples. Upon identification of uranium particles, the morphology and elemental as well as isotopic information were requested. Two instruments, a Scanning Electron Microscope (SEM) and a Secondary Ion Mass Spectrometry (SIMS) had to be deployed as all this information cannot be retrieved within one single instrument. The major challenge when moving the sample material between the instruments was to relocate exactly the same particle within a matrix of millions of other particles. The SIMS instrument was used to find relevant particles, to make the isotopic measurements and to add special markers for later identification of exactly the same particles in the SEM instrument. After this the sample material was transferred to the SEM where the particle of interest could be relocated by the markers from the SIMS. With this method it was possible to quickly move the sample material between the two instruments while being able to fully characterise particles with both techniques for sizes down to 200nm.

3.3.4. Operation of the Euratom On-site Laboratories (OSLs) at the La Hague and Sellafield reprocessing plants

There are two large-scale reprocessing plants in Europe: La Hague in France and Sellafield in the United Kingdom. Under the Euratom Treaty, the European Commission has the duty to assure that nuclear material is only used for declared purposes. One of the methods to provide precise control on the large flows of nuclear material through the reprocessing plants is the independent measurement of samples routinely taken at key measurement points. In order to deal with the large number of samples taken at both La Hague and Sellafield, the safeguards authorities (DG ENER)

opted for the installation of individual laboratories at the respective sites of the reprocessing plants. OSLs offer the Euratom safeguards inspectors independent analytical capacity of high quality and provide results within a short time. The OSLs not only measure the samples which are routinely taken throughout the year, they also analyse the substantial numbers of samples taken during the Physical Inventory Verification (PIV) campaigns. Typically some 700 – 900 samples from the input solution, the process flow and the Pu products are analysed annually by radiometric, chemical and mass spectrometric methods. The laboratories furthermore provide technical assistance to the Euratom safeguards inspectors and do non-routine measurements when requested. Maintenance work is performed continuously to keep the laboratories in good working order. Special projects have been defined to modernise the laboratories. One example of a finalised refurbishment project was the installation of a new thermal ionisation mass spectrometer at the OSL Sellafield, another project for refurbishment of the Non Destructive Analysis setup within the OSL is being negotiated. Such activities are complex tri-partite projects between ITU, DG ENER and Sellafield Ltd. In 2010, ten years of OSL operation was highlighted by a symposium gathering EU Commission services, the IAEA and nuclear facility operators.

3.3.5. Analytical service

Within the Analytical Services of the Nuclear Safeguards and Forensic unit some 500-700 nuclear sample analyses are made annually. The customers are both in-house and external. Most of these samples require several analytical measurements. This can include a variety of NDA measurements, such as Hybrid K-edge densitometry, calorimetry, neutron coincidence counting and gamma spectrometry, as well as isotopic analyses by mass spectrometry such as TIMS, SIMS, and ICPMS. IDMS and titration are used for determining the concentration of U and Pu. In addition ICPMS is used to determine trace element distribution in U, Pu, as well as UPu samples. In order to perform isotope dilution mass spectrometry a well characterized spike material is the basis of the method. The Action is participating in such verification campaigns for IRMM and IAEA. The analytical work is accredited by ISO 17025 and both internal and external audits are made annually to verify the compliance with the accreditation. Furthermore there are also yearly participations in different round robin exercises to further control and validate the performance of the used analytical techniques.

3.3.6. Additional Protocol Exercise (APEX) for IAEA safeguards

Under the EC Support Programme to IAEA, a training course on Complementary Access (called Additional Protocol Exercise APEX) is organised annually since 2012 with support by DG ENER. The aim is to familiarise IAEA inspectors with complementary access (CA) procedures in a nuclear R&D environment.

CA is recognized as one of the most powerful Safeguards measures to assure the absence of undeclared nuclear material and activities in the territory of States. Preparing and conducting CA in a complex R&D environment remains one of the key challenges for IAEA safeguards in evaluating States' nuclear capabilities, the scale of their nuclear fuel cycle and plausible acquisition pathways for obtaining nuclear

material for nuclear explosive devices, as key steps in designing State-level approaches.

The developed scenarios aim at enhancing trainees' abilities in using CAs to identify possible indicators of activities in the area of advanced R & D technologies, such as advanced chemical separation techniques or material science involving nuclear material. The training course involves five Units at ITU, making full use of a wide variety of R&D topics relevant for CA inspections.

4. Further Information

4.1. Integration and Networking

JRC internal collaborations

Collaboration exists among the following JRC institutes; **ITU, IRMM, IES/ISPRA** and **IPSC/ISPRA (now unit E.8 of ITU)**:

- **ITU and IRMM** have been collaborating on verification of LSD spike materials for nuclear accountancy purposes. Further collaborations have been made on a new mass spectrometric method developed at IRMM (MTE method). Measurements were made at ITU of the Ti isotopic in targets for neutron cross-sections measurements at IRMM. There has also been joint work on preparations of the IRMM inter laboratory comparisons for particle measurements (NUSIMEP 7), for isotopic composition of a U/Pu solution at low concentration (NUSIMEP 8) and a synthetic U/Pu input solution (REIMEP 17).
- Collaboration between **ITU** and **IES/ISPRA** on the test work of a Single Particle Analysis and Sizing System (SPASS) for elemental and isotopic particle analysis.
- Collaboration between **ITU** and **IPSC/ISPRA** on Pu isotopic measurements on high burn up fuel in La Hague.
- In addition there are many collaborations and support to the other nuclear safety actions within ITU. A large part of this is made by providing analytical support on nuclear materials.

Networking with external organisations

- Work with **DG-ENER**, (On-site laboratories, training, analytical measurements).
- Work with the **IAEA**, (EC support program tasks and analytical work for Safeguards purposes).
- Collaboration on LG-SIMS evaluation with **NORDSIM**, Stockholm.
- Collaboration on LG-SIMS evaluation with **the University of Western Australia.**
- Development of new HKED software with **Los Alamos National Laboratory** (LANL). Discussions are also held on extending the collaboration to other areas including SIMS analysis.
- Collaboration with **the French Atomic Energy Commission** (Commissariat à l'énergie atomique – CEA) on particle analysis.
- Collaboration with **the Japanese Atomic Energy Agency** (JAEA) on nuclear and environmental analysis. An exchange of expertise has been made between ITU and Tokai Plutonium Fuel Fabrication Plant (PFPF) and Tokai Reprocessing Facility (TRP).

- Collaboration with **New Brunswick Laboratory** (NBL) on U and Pu standard evaluation
- **Westinghouse,** Fa. Starck Boron isotope measurements on boric acid and boron carbide.

4.2 List of Competitive Activities

Participation in Indirect Actions:

- Support to the TACIS program.

Third Party Work:

- Contract with ABACC for environmental particle analysis
- Contract with KINAC for environmental particle analysis
- Contract with IAEA for sample analysis.

Administrative Arrangements (AA):

- AA with DG-ENER for production of swipe sample kits and for sample analysis.
- AA with DG-ENER for the operation of the two On-site laboratories at La Hague and Sellafield.
- AA with DG ENER for the refurbishment of two gloveboxes in the On-site laboratory at Sellafield.
- AA with DG-ENER for the in-field physical inventory verifications at LEU plants with the Compucea method.

Agreements:

- Agreement with JAERI in collaboration in R&D programs
- Agreement with CEA in collaboration in R&D work

4.3. Mobility and training of researchers

The action has provided the following training for inspectors and researchers:

- Training of IAEA inspector analysts for work at the OSL of the Rokkasho reprocessing plant. This includes training in operation of both analytical equipment and nuclear chemistry.
- The Action has provided training and guidance for a Ph.D. student. The thesis was defended at the end of 2009.
- An advanced training course in HPTA measurements has been held for Euratom inspectors.

EUROPEAN COMMISSION
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JOINT RESEARCH CENTRE

Ex-Post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2013

Action *n°* 53109 - EUCBRNS - EU CBRN Security

Action Leader: Said Abousahl, A.4

Authorising Officer: *Said Abousahl, A.4*

Dir. A — Policy Support Coordination (Brussels)

0. Policy Area

Policy Theme: 5. EURATOM programme
Agenda N° & Title: 5.2 Nuclear security
Sub-agenda N° & Title: 5.2.3 Nuclear Safeguards, Additional Protocol and Combating Illicit Trafficking

1. Rationale of the Action:

Under this Action, the JRC brought
The EU CBRN Action Plan (2009), implemented under supervision of DG HOME, aimed at strengthening CBRN security in the European Union. Its overall goal was to reduce the threat and damage from CBRN incidents of accidental, natural and intentional origin. The JRC provided important technical support to DG-HOME on the evaluation of some actions, and participated directly in the implementation of an important part of the CBRN AP circa 147 actions, mainly in the field of RN security
The appearance, for the first time in the 7th Research Framework Programme, of a dedicated area of R&D in CBRN security. JRC provided technical support to DG-ENTR on the definition of projects and is involved in some of the projects as a member of consortia.
The growing support of the JRC to the EU CBRN Centres of Excellence, a risk mitigation and capacity building Initiative managed in cooperation by DG DEVCO and the EEAS, launched in 2009 under the Instrument for Stability in response to the EU Strategy against proliferation of weapons of mass destruction and their means of delivery (WMD) adopted by the European Council on 12 December 2003. The JRC provided large technical support, covering from direct project implementation, participation of experts in national and regional meetings, drafting term of references for projects implemented by MS consortia, evaluation and quality control of deliverables, monitoring, communication, knowledge management, etc.
The JRC supported complementary EU actions at the international level with the International Atomic Energy Agency (IAEA), CTBTO, WHO and OPCW through Joint Actions, which contributed to enhance the coordination and coherence between the different activities of different donors. In this scope, we can include the role of the JRC in co-chairing the Border Monitoring Working Group (BMWG), which coordinates the activities on combating illicit trafficking of radioactive and nuclear materials and border control. The BMWG was created in 2006 and composed of representatives of the European Commission, EEAS, IAEA, United States Department of Energy. Also the Export control outreach activities are coordinated through a dedicated WG established by EC (DEVCO, TRADE, JRC), BAFA (German Authority in charge of export control and implementing body of EU outreach activities) and US (DOS, DOE). JRC is the technical body of the EU in this WG. In the field of RN security, bilateral cooperation with US, Japan, China, and Canada are ensured through bilateral Euratom agreements where the JRC is the Euratom coordinator for the implementation.
The work of the action had internal and international dimensions, both directly related to EU policy support. Inside EU, one goal was to provide technical support to EU CBRN actors (EC-DGs, EEAS, MS) and to ensure a close coordination with them. Outside EU, the action focused on technical support to the implementation of the IFS projects mainly through the CBRN CoE initiative as well as on the technical coordination with the main international players.
As CBRN security involves several institutes across the JRC, the action EUCBRNS is an excellent example of successful coordination ensuring effective implementation of horizontal projects.

2. History and development of the Action:

This action has evolved from the support of the JRC to several initiatives and strategies of the EU, bringing together areas in which the JRC had accumulated expertise through several years of scientific and technical support to EU policy. Some important ones, already described in the rationale, were the approval of the EU CBRN Action Plan in 2009, the launching of the EU CBRN Centres of Excellence Initiative also in 2009, and the strengthening role of the BMWG since 2006. Several projects are nested in these activities and have contributed for the accumulated results of the Action.

3. Description of the Action

Inside the EU, the EUCBRNS action focused on provision of technical support to DG HOME on the evaluation of some actions within the EU CBRN Action Plan and moreover, it covered the support to the implementation of agreed actions; namely: evaluation and comparison of the performance of available detection equipment relevant to nuclear security (ITRAP+10, now in Phase 2), creation of an European Nuclear Security Training Centre (EUSECTRA), support the IAEA in improving the IAEA ITDB, develop a CBRN Glossary, benchmarking of dispersive codes for the estimation of RDD impact, development of a hands-on and virtual reality based training capability for RN detection, among other actions.
Additional important activities under this action were related to the coordination of CBRN security related activities with other services of the European Commission (e.g. DG HOME, DG ENER, DG ECHO, DG TRADE, DG TAXUD, DG SANTE, DG ENTR), EEAS, EU MS and key MS technical organizations to achieve optimal results and avoid any unnecessary overlap.
Outside the EU, the Coordination and cooperation with the main stakeholders involved in the CBRN CoE initiative, including the United Nations implementing partner UNICRI was ensured. The several tasks of the JRC in the Initiative range from technical support to the secretariats and the national and regional meetings, to the evaluation and quality control of the implementation of projects.
Coordination and cooperation with international organizations, as for example IAEA and its network of (national) 'Self-sustaining Nuclear Security Support Centres (NSSC)', WHO/FAO/OIE ("One World, One Health") and OPCW, was essential to ensure good quality assistance and avoid duplication of efforts, and has been ensured by regular information sharing meetings. Furthermore, the coordination of the CBRN CoE initiative among National Teams, international/regional organisations and other international partners, based on the experience of the Border Monitoring Working Group and through the EU outreach program has also been ensured.
This Action also contributed to the implementation of bilateral Euratom agreements with US, Japan, China and Canada in the area of RN security, and to the internal JRC coordination in this field ensuring effective implementation of horizontal projects.

3.1. Clients and Stakeholders

Major clients for this action were DG HOME, DG DEVCO, EEAS, Member State authorities, the International Atomic Energy Agency (IAEA)

3.2. Major Objectives, deliverables and impacts

Objective 1: Support to the JRC institutes on implementation of agreed actions under the EU CBRN Action Plan and to provide technical support for evaluation of actions under the EU CBRN Action Plan which are implemented by MS.

Deliverables: This Action accompanied the development of several Administrative Arrangements with DG-HOME: Evaluation and comparison of the performance of available detection equipment relevant to nuclear security (ITRAP+10); Creation of a European Radiological/Nuclear Security Training Programme for the Law Enforcement Community (EUSECTRA); Support IAEA in improving the IAEA ITDB; Benchmarking of dispersive codes for the estimation of RDD impact; Development of a hands-on and virtual reality based training capability for RN detection. More than 100 portable and fixed radiation detection equipment have been tested by the ITRAP project, in close collaboration between the US and the EU. A larger number of reports have been issued to the partner DGs and EU services, to the manufacturers for confidential benchmarking purposes and to the international standardization organisations such as CEN and IEC.

Impacts: The results of this research were of direct use for the implementation of the EU CBRN Action Plan, for supporting innovation and technological development for the CBRN end users and for strengthening the international cooperation in CBRN security.

Objective 2: To provide technical support for effective implementation of the EU CBRN Risk Mitigation Centres of Excellence Initiative.

Deliverables: The EUCBRNS Action provided a support to DG DEVCO in the implementation of the EU CBRN Risk Mitigation Centres of Excellence Initiative through participation of CBRN experts in national and regional meetings, collaboration on the development and implementation of the integrated CBRN needs assessment questionnaire in partner countries, analysis of regional project proposals, contribution to the preparation of terms of references for selected projects (when not implemented by JRC), contribution to ensuring quality control of executed projects in the partner countries/regions, communication between all stakeholders by developing a communication strategy and hosting the public and private portals, which are linked with the knowledge management strategy and will be the basis for a future CBRN e- library, and through ensuring evaluation and quality control of projects implemented by EU MS consortia or other organizations or partners. The JRC also provided, at the end of 2013, when the initiative had over 30 projects running, a mapping of synergies and potential overlaps of the projects in selected regions.

Impacts: The CBRN CoE Initiative launched in 2009 has progressed, with the contribution of JRC, to play an important role in global security, with more countries joining from 8 regions to a current total of 48 partners, and numerous candidates. A recent report from the European Court of Auditors has confirmed the importance of the work done and considered the Implementing Partners (JRC and UNICRI) to be the correct choices for the nature of the tasks. The initiative has trained more than 1500 participants from partner countries in capacity building activities.

Objective 3: Coordination of activities with stakeholders: Coordination and follow-up of the implementation of bilateral agreements with EU MS; Coordination of the implementation of bilateral Euratom agreements with US, Japan, China and Canada in the area of RN security; Implementation of the Practical arrangement with the IAEA in the field of nuclear security and follow up of the Border Monitoring Working Group activities.

Deliverables: The JRC is working actively with institutions in the MS, by the progressive setting up of a growing number of practical agreements and MoUs linked to the CBRN areas. The practical arrangement between the EC, represented by the JRC, and the IAEA

in the field of nuclear security was finalized in the end of 2013 and is currently under implementation. Regular meetings take place for information exchange in Nuclear Security activities. JRC is also co-chairing the Border Monitoring Working Group (BMWG), which coordinates the activities on combating illicit trafficking of radioactive and nuclear materials and border control.

Impacts: The participation of the JRC in high level CBRN information exchange, border monitoring and export control coordination groups has contributed for avoiding duplications and building up on complementary work in order to maximize the benefit from the allocated resources.

3.3. Major Highlight(s)

The JRC is co-chairing, with the US Department of Homeland Security, the Border Monitoring Working Group (BMWG), which coordinates the activities on combating illicit trafficking of radioactive and nuclear materials and border control. JRC also developed, through its very active participation in this WG, the first joint syllabi of the EU, the US and the IAEA for training border guards and trainers.
A recent report from the European Court of Auditors has confirmed the importance of the EU CBRN Initiative for global security and considered the Implementing Partners (JRC and UNICRI) to be the correct choices for the nature of the tasks. The initiative has contributed to improve the response to CBRN threats in recent critical events, for example during the ebola crisis in West Africa, where mobile labs previously deployed were among the first to be used for field diagnosis.
The ITRAP+10 project has finished the evaluation of over 100 portable and fixed equipments for radiation detection, issued tailored reports for the different stakeholders and EC DGs and EU services, and is contributing to the international standardization process with the information gathered. The next step (transferring the expertise to MS laboratories) is already ongoing.

4. Further Information

4.1. Integration and Networking

The JRC is co-chairing the Border Monitoring Working Group (BMWG), which coordinates the activities on combating illicit trafficking of radioactive and nuclear materials and border control. The BMWG was created in 2006 and composed of representatives of the European Commission, EEAS, IAEA, United States Department of Energy. Also the Export control outreach activities are coordinated through a dedicated WG established by EC (DEVCO, TRADE, JRC), BAFA (German Authority in charge of export control and implementing body of EU outreach activities) and US (DOS, DOE). The JRC participates also regularly in the Nuclear Security Information Exchange Meetings at the IAEA.

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Ex-post evaluation of the nuclear activities of the Joint Research Centre in the context of the Seventh Framework Programme of the European Atomic Energy Community (Euratom) 2007 –2013

Action 53201 – NUSIM Nuclear Fuel Cycle Simulations
Action Leader: Paolo Peerani

Authorising Officer: W. Janssens (Nuclear Security Unit)
Leading Institute for Transuranium Elements (ITU)

0. Policy Area

Policy:	5.	Euratom Programme
Agenda	5.3	Nuclear Security
Sub-agenda	5.3.1	Nuclear Safeguards, Additional Protocol and Combating Illicit Trafficking

1. Rationale of the Action:

JRC has a long tradition of scientific and technical support to the implementation of nuclear safeguards. This support is extensively provided to the Commission services in charge of the implementation of the Euratom Treaty (DG ENER) and in the framework of the Non-Proliferation Treaty to the International Atomic Energy Agency (through the Support Programme and EEAS).

More recently an evolution of the JRC expertise in this field has been driven by increased political and social concerns about security in general and nuclear security in particular. New projects focus in the anti-terrorism field to the detection of illicit trafficking of nuclear and other hazardous materials.

The diversity and complexity of the nuclear fuel cycle has clearly evidenced the fact that not all the real conditions can be reproduced in laboratory experiments. Therefore there is a strong need to reproduce and predict the behaviour of instruments and systems through physical modelling and computational simulation.

Safeguards approaches are moving towards an increased use of monitoring to automatically control nuclear activities in facilities such as reprocessing or enrichment and to follow processed nuclear materials. It can reduce requirements for inspector presence and increase safeguards effectiveness both in terms of timeliness and sensitivity. Monitoring involves the integration of data from a variety of sensors (pressure, mass, neutron, gamma) to control activities involving material in transit or in process. The innovation lies mainly in recognising anomalies in the behaviour by integrating the different types of data. The analysis and interpretation of the large amount of process data in complex facilities requires also system modelling.

This action has contributed to the development of methodologies, software tools and methods for nuclear security, in particular for the evaluation of nuclear safeguards effectiveness, proliferation resistance of existing and advanced nuclear energy systems including related fuel cycles and research reactors and the concept of safeguard-by-design.

NUSIM has supported EU's nuclear security policy by focusing on detection methods and instrumentation, their evaluation, comparison and categorisation striving for harmonisation and standardisation in the field (testing campaigns for the evaluation of detection equipment, testing of innovative sensors). In line with the recommendation of the DG HOME 2009 CBRN Action Plan, NUSIM has established a pilot training centre for detection of illicit trafficking of radioactive and nuclear material. Training courses on nuclear security for first responders and train-the-trainers have been provided in the framework of EUSECTRA. The courses have been hold in close coordination with other major international support programs (i.e. the IAEA, the US Second Line of Defence (SLD) program and the EU Council).

In line with EU’s nuclear security policies, NUSIM has strongly supported DEVCO’s outreach activities by implementing safeguards and security projects in the CIS

countries, north and Sub-Saharan African countries, Central Asia and South East Asia. Close coordination with the IAEA, US DoE and DoS and other international donors was performed through the Border Monitoring Working Group.

Export control on dual use goods is a key barrier to proliferation. DG TRADE requested the JRC to provide technical support for the improvement and harmonisation of EU export control system and to "Art.23 Coordination Group" activities; to contribute to the formulation of Dual use export control Guidelines; to reinforce and improve a European Pool of Experts, available to advice EU-27 Administrations on specific cases of dual use technology export; to contribute to the development of technical training modules within the EU in-reach training programme; to provide support in the context of the nuclear suppliers group, as well as in other international regimes.

Finally the action supported networking and international associations namely the European Safeguards Research and Development Association (ESARDA).

2. History and development of the Action:

During FP6 the entire institutional activity of unit G08 was included in a single action "Non-Proliferation of and nuclear safeguards". From January 2007 at the beginning of FP7, the NPNS action has been split in four actions: NUMAMET, PhyMod, VERTEC and AMENUS. This structure has been stable for two years: 2007 and 2008 (with the addition of action TENS in 2008). The NUSIM action was created in January 2009 during a rearrangement of the activities of unit G08 (at that time, now E08), inheriting all the activities of the previous actions PhyMod (NDA, Monte Carlo modelling, process monitoring), TENS (nuclear security and training) and part of those of AMENUS (ESARDA, proliferation resistance of Gen-IV systems, system analysis). The action with all the associated macro-objectives has remained pretty stable till the end of FP7 (December 2013); the only changes, occurred in 2012, were the transfer of proliferation resistance activities to IANUS and the activity on export control of dual use items from IANUS. For simplicity and clearness of reporting the activities on PRPP, held first in AMENUS, then in NUSIM and finally in IANUS, will be all integrated in the IANUS ex-post report, so the NUSIM activities in this field are not reported below.

3. Description of the Action

3.1. Clients and Stakeholders

Customer/users (outside the European Commission):

- ESARDA
- GIF
- IAEA
- Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
- Los Alamos National Laboratory
- US Department of energy (DoE)
- US-Department of Homeland Security (DHS/DNDO)
- Istituto Nazionale di Fisica Nucleare (INFN)
- Fraunhofer Institute (FhG-INT)

Customer DGs (inside the European Commission):

- Energy – ENER
- Migration and Home Affairs – HOME

- International Cooperation and Development – DEVCO
- European External Action Service – EEAS
- Trade – TRADE
- Taxation and Customs Union – TAXUD

3.2. Major Objectives, deliverables and impacts

Objective 1: Improvements of performances of NDA techniques, including modelling and simulation by Monte Carlo techniques

Deliverables

- Construction and characterisation of SNMC (Scrap Neutron Multiplicity Counter) for measuring plutonium scrap samples in MOX fabrication plants
- Design of a neutron counter for monitoring the reception of plutonium oxide container at the Melox plant
- Numerical calibration using Monte Carlo techniques of several neutron counters for Euratom and IAEA inspections on various nuclear plants (D4 and D5 in Sellafield, D0 in Marcoule, Guinevere in Mol, collar for VVER elements and fast-UNCL IAEA collar)
- Feasibility study of a monitoring system for a dry storage for RBMK spent fuel in Lithuania
- Development, testing and inspector training of Xfuelbuilder, an automatic interface to describe the geometry of a fresh fuel element, build a Monte Carlo model, run the simulation and compare to declarations
- Testing and calibration of the IAEA glove-box neutron monitor AMGB for the Rokkasho MOX plant
- Construction, testing and calibration of the multiplicity counter for the UMCS station in the Sellafield Magnox store
- Under the EC support programme to IAEA (Task EC-A-1362), modelling and conceptual design of an innovative neutron collar based on liquid scintillators as replacement of the UNCL based on He-3 technology
- Report on the analysis of the application of the P-DET detector to the verification of gross defects in spent BWR elements in reactor ponds
- Final report of an international benchmark to validate Monte Carlo simulation techniques for neutron counters and data analysis software
- Prototype of a new acquisition/data analysis system for digital processing of pulse trains from neutron counters
- Development, testing and validation of a simulator (pulse generator) of neutron counter and of a LIST mode analyser (FPGA acquisition card and software)
- Training courses on active neutron counting for nuclear inspectors (typically once per year)
- 24 peer-reviewed publications

Impacts

Notwithstanding the strong R&D component of this activity (demonstrated by the large number of scientific papers), the number of technical solutions offered to DG ENER and to the IAEA, enabled these authorities to improve their inspection capabilities and to enhance their techniques for the verification of nuclear material in plants.

JRC has been one of the main pioneers in the use of Monte Carlo techniques in NDA for safeguards. It is thanks to the excellent results obtained in modelling the neutron counters that now numerical calibration has become a fully accepted methodology. Numerical calibration finds more and more in-field applications where it has often replaced the classical empirical calibration in all the cases where appropriate calibration standards were not available. JRC has also engaged a lot in building-up a culture in Monte Carlo methods at ENER and IAEA and in the development of easy user-friendly tools enabling a wider use by inspectors.

In the last years the research on neutron counting has focused primarily in the development of detectors based on alternative technologies to He-3, duel to the recent lack of availability of this material. JRC, in addition to carrying out its own R&D program on novel neutron detection technologies, has been at the leading edge of the testing and evaluation of new neutron detectors for safeguards and security applications.

Objective 2: Development of process monitoring and radioactive solution measurement techniques for nuclear safeguards

Deliverables

- Development of DAI (Data Acquisition and Interpretation), a software for the acquisition of data from various process monitoring sensors and their analysis in order to detect anomalies or diversions with safeguard implications
- Installation of a process monitoring system at the THORP reprocessing plant (Sellafield, UK) in support to Euratom inspections
- On-site support to Euratom inspections for the use of the process monitoring system at THORP (Sellafield), UP2 and UP3 (La Hague)
- Improvement of the process monitoring system in La Hague (replacement of loggers)
- Solution Monitoring System at the Rokkasho Reprocessing Plant and at the Tokai Mura Reprocessing Plant in Japan in support to IAEA inspections
- Development of the first modules of SAT (Safeguard Analysis Tool), a software that will integrate and allow interoperability of the existing monitoring systems (DAI/PI, RADAR/CRISP) used at DG ENER
- Design, construction, installation and commissioning of an unattended system to monitor the movements of plutonium samples to/from the Q29 storage and of the Safkeg loading station in the Magnox plant in Sellafield (UK)
- Verification of the calibration of input accountancy tank at the THORP reprocessing plant (Sellafield, UK)

- Development and validation of VOLCAM.net for tank calibration and of a software for calibration in continuous mode
- Training courses on tank calibration for nuclear inspectors (twice per year) and process monitoring techniques (once per year)
- Development of a concept for improved safeguards at GCEP's (Gas Centrifuge Enrichment Plants) based on real-time monitoring of load cells; validation performed through real data from the URENCO plant in Capenhurst (UK)
- Implementation of a load cell monitoring system at GB-II plant in Pierrelatte (F) and support to IAEA and Euratom during PIV inspections
- Construction of a test-bed facility for the simulation of the operation of a GCEP load cell monitoring system
- Development of a model for simulating a GCEP, optimise a centrifuge cascade and estimate the enrichment production capability of a plant in normal operation and in hypothetical diversion conditions
- Conceptual design, set-up and construction of a new laboratory AS3ML (Advanced Safeguards Modelling, Measurement and Monitoring Laboratory) in collaboration with the other actions of E08; operational in 2015.
- 6 peer-reviewed publications

Impacts

This block of activities has a strong component of operational support (often including on-site assistance) to inspection activities both for DG ENER and IAEA. It relies on a long experience on safeguards of critical facilities, in particular on reprocessing plants. Due to the strong sensitivity of enrichment technology new developments aim to transpose this expertise to the safeguards of GCEP's; initially this activity was mostly limited to R&D, but recently it started to be implemented in-field, in particular to the new plant of GB-II in France.

The application of process monitoring at safeguarding GCEP has brought a fundamental step of innovation and has the potential to change completely the conceptual approach for this type of installations. The difficulty to maintain the control on a continuously varying mass balance in a plant with bulk material processing can be overcome by a real-time monitoring of the process in strategic points that has the potential to indicate and highlight anomalous behaviours and any deviations from ordinary operation that could bring to diversion of nuclear material.

Objective 3: Improve detection capabilities of illicit trafficking of nuclear and radiological material

Deliverables

- Design, construction and operation of two new laboratories (static and dynamic) for testing of nuclear detection instruments and verification of their compliance with international standards

- ITRAP+10 project, under AA with DG HOME: testing of approximately 50 models of detection instruments (portals, radioisotope-identifiers, searchers, pagers) with respect to ANSI, IEC and NSS1 requirements
- Definition, in collaboration with US-DHS and US national laboratories, of unified testing procedures for proficiency tests of nuclear detection equipment
- Participation to the FP6 EURITRACK project for the development of an active neutron interrogation system to detect explosives and other illicit materials in cargo containers (development of the information system)
- Participation to the FP7 SCINTILLA project for the development of a toolkit of innovative detection equipment; the role of JRC was testing and evaluation of the developed instruments
- Study (under Administrative Arrangement (AA) with DG-JLS of the preparedness to face radiological/nuclear threats in the EU27
- Organisation of a workshop on Radiological/Nuclear vulnerability
- Set-up and operation of the EUSECTRA (EU Radiological/Nuclear Security Training Centre) facility in Ispra and support to the establishment of the sister facility in Karlsruhe
- Development of a joint training curriculum for first responders on detection of N/R material in collaboration with the IAEA and the US-DoE/SLD (US Department of Energy, Second Line of Defence)
- 21 training courses on detection of nuclear/radiological material delivered in the reporting period
- Completion of the implementation of 9 projects funded by the TACIS programme (under AA's with DG DEVCO) in the field of nuclear security and safeguards: Tasks A (Improvements to NMAC at Mayak Reprocessing Plant), Task B (Establishment of testing lab at VNIIA for certification of NMAC instruments), Task C (Development of sealing systems at Rosatom), Task E (NMAC of spent fuel at Andreeva Bay), Task G (Computerised NMCC for VVER and RBMK NPPs in Kursk and Kalinin), Task J (Enhancement of NMAC at the Medzamor NPP), Task H and I (Ukrainian and Armenian border crossing stations), Task N (Support to the training centre in Snezhinsk)
- Implementation of projects funded under the Instrument for Stability (under AA's with DG DEVCO) in the field of nuclear security: task B07 (Belarus border crossing station – completed), task MED (Border management monitoring in Algeria and Morocco), task U09 (Border monitoring in Uzbekistan – completed), task T09 (border monitoring in Tajikistan), task SEA (Border management monitoring in South East Asia: Cambodia, Philippines, Lao PDR and Thailand), Task DRC (border monitoring in democratic Republic of Congo)
- Implementation of projects under the CBRN Centre of Excellence initiative funded under the Instrument for Stability (under AA with DEVCO): Project 21 aiming at strengthening capacity building in border monitoring and increasing interagency coordination implemented in South East Asia and African Atlantic Façade and project 28 aiming at improving security and safety of radioactive sources jointly implemented with IAEA in South East Asia

- Technical support in the implementation of the CBRN Centres of Excellence (under AA with DG DEVCO): perform need assessment missions in partner countries, support in the establishment of national action plan, drafting of new project Terms of Reference, technical evaluation of on-going projects (including ex-post), impact analysis of completed projects, ensure international coordination
- Bi-annual participation to the Border Monitoring Working Group and follow up of coordinated activities (in country joint assessment missions, organisation of joint workshop and training, development and revision of joint training curricula)
- Development and testing of a prototype tool for virtual training in nuclear security and safeguards
- 12 peer-reviewed publications

Impacts

The activities under this objective constitute a broadening of NUSEC competences in nuclear metrology from safeguards to security in a broader sense (including border control and fight to illicit trafficking).

During this period JRC has acquired a leading role in Europe in testing and evaluation of detection equipment; this is particularly due to the huge international resonance of the ITRAP+10 project (even cited by the White House as a success story of US and EU collaboration in improving nuclear security worldwide). Based on the infrastructures and competence developed in ITRAP+10, we have also extended to the assessment of innovative instruments (as in the SCINTILLA project). Moreover this constitutes the first step in view of establishing a European system of certification for this category of instruments.

The competence developed in the detection equipment has been also instrumental in building the training capacities that have allowed to deliver a large amount of training courses to front-line officers, and even more important to support capacity building through the train-the-trainer scheme.

Finally the scientific background, coupled with the training, has allowed JRC to support DG DEVCO in the implementation of a large number of assistance projects aiming in building capacity and improving nuclear security in third countries.

Objective 4: Networking, training and knowledge management in nuclear safeguards

Deliverables

- Organisation on alternate years of the ESARDA Symposium (Aix-en-Provence 2007, Vilnius 2009, Budapest 2011 and Bruges 2013) and of the ESARDA Annual Meeting (Luxembourg 2008, 2010 and 2012) including publication of the proceedings
- Management of the ESARDA website
- Publication of the ESARDA Bulletin (13 issues in the reporting period)

- ESARDA course on “Nuclear Safeguards and Non-Proliferation” hold on yearly basis, development of the associated curriculum and publication of the syllabus (7 sessions in Ispra in the reporting period, plus a session in Kuala Lumpur funded by DG DEVCO)
- Organisation of a Workshop on “NDA techniques for Euratom inspections” in Luxembourg
- Co-organisation of a Workshop on “Gamma Spectrometry techniques for U/Pu isotopic measurements” in Oak Ridge (USA)
- Additional Protocol workshops to train IAEA inspectors on Complementary Access issues on Ispra nuclear facilities (3 sessions in the reporting period)
- Coordination of the EC support programme to IAEA

Impacts

ESARDA constitutes the main international forum for nuclear safeguards at European level and connects with INMM, its US equivalent. JRC contributes to ESARDA with much more that simple participation: it guarantees permanently the general Secretariat, provides chairmanship of some technical working groups, assures the maintenance of the website and the publication of the Bulletin. ESARDA is the main channel allowing JRC to network with all the major stakeholders in the safeguards field.

JRC operates the EC-SP since its start in 1981. Technical contributions (and hence the coordination) involve two JRC institutes: IRMM and ITU (E07 and E08) as well as DG-ENER (EURATOM Safeguards). Areas of work include: (a) NDA: Equipment, Modelling and Measurements; (b) Sealing, Containment and Surveillance; (c) Analytical and Reference Techniques; (d) Support to IAEA Operations; (e) Information Technologies for Non-Proliferation; (f) Concepts and Approaches and (g) Training. Between 2007 and 2013, EC-SP expanded from 28 to 46 running tasks. The Support Programme is formally reviewed twice per year by the IAEA and the European Commission. To foster cooperation in Nuclear Safeguards, and in particular within the EU, all coordinators of the ten EU and US Support Programmes are invited to participate in the review meetings. As a result of the wide exchange of information, it was possible to initiate Joint projects meeting the needs of IAEA and EURATOM Safeguards. JRC researchers also participate regularly at IAEA sponsored workshops, technical meetings, expert groups, networks, etc.

Objective 5: Support in export control of dual use items

Deliverables

- Technical training events, in support to the EU in-reach training programme on dual use export control, including the organisation of an international technical seminar with US-DoE and EU MS licensing authorities, with publication of proceedings: 6 events in the reporting period
- Build-up and management of the EU dual-use Pool of experts replying to requests of advice from EU-28 export control administrations

- Technical support to DG TRADE in Art.23 Coordination Group and Council WPDU, with inter-alia monthly analysis of denials and contribution to EU harmonisation and Guidelines
- Technical reports on the Harmonisation Intangible Technology transfers
- Participation to Nuclear Supplier Group, Australia Group and other regime meetings with provision of technical support and comments to proposals
- Maintenance of the NSG website
- Technology guide for laser isotope separation
- Development of the new ESARDA Export control Working Group, with an average of 35 participants from nuclear regulators, universities, IAEA, suppliers and research organisations

Impacts

The activities of JRC in the field of export control in the period of reference have been very successful. The successful and acknowledged activities included inter alia: the EU Pool of Experts on dual-use support to licensing authorities, technical advice to DG services, analysis of denials, support to EU role in International export control regimes, amendment of Regulation 428/2009 on dual-use goods; various seminars for licensing authorities (EU and Enlargement & Integration) with over 80 EU participants in total; evaluation of the long-running EU export control outreach programme; collaboration with US DOE and IAEA; development of the new ESARDA Export control Working Group.

Close collaboration was ensured with IANUS action and STANP project, also under an Administrative Arrangement with DG TRADE, as well as other JRC institutes.

The EU dual-use Pool of experts and technical seminars were officially acknowledged in Council Working Party on Dual Use goods meetings, as well as mentioned in the Commission Communication to the European Parliament and Council COM(2013) 710 on Implementation of Regulation (EC) No 428/2009 setting up a Community regime for the control of exports, transfer, brokering and transit of dual-use items.

3.3. Major Highlight(s)

- The ITRAP+10 project has allowed JRC to become the major European actor in evaluation and testing of nuclear detection equipment and is the first step in view of establishing a European system of certification for this category of instruments.
- The establishment of a nuclear/radiological Security Training Centre (EUSECTRA) derived from a strong consensus from Member States expressed to HOME through the CBRN Task Force.
- The support of JRC to DG DEVCO has been fundamental for the implementation of projects in the field of nuclear security and safeguards within the different funding schemes (TACIS, IfS, INSC and CBRN-CoE).
- The Magnox project is a remarkable example of integrated system for safeguard of a complex nuclear facility.

- The long experience derived from the R&D in solution/process monitoring for safeguards of reprocessing plants has served as basis to develop new JRC expertise in the field of safeguards for enrichment plants.
- NUSIM experts are recognised leaders in the field of Monte Carlo simulation of NDA systems and the technique of numerical calibration of neutron counters has got full recognition and become of routine use for safeguards inspections both at DG ENER and IAEA.
- The competence of JRC in export control is nearly unique in Europe and provides an irreplaceable support to DG TRADE.
- The ESARDA course on “Nuclear Safeguards and Non-Proliferation” has filled a gap in a field not adequately followed by universities and has become one of the cornerstones in training and education for nuclear safeguards.

4. Further Information

4.1. Integration and Networking

The action operated in close collaboration and complementarity with all the other actions of JRC involved in Nuclear Safeguards, in particular the other three actions of E08 (NUMAMET, NUVER, NUTRASEAL and IANUS), and the two actions of E07 in Karlsruhe.

As far as networking, the importance and role of ESARDA have been already described above.

4.2 List of Competitive Activities

A list and short description of the competitive activities linked to the action (2010 to 2013)

Support to Commission (AA’s with customer DG)

DG ENER 30271 Development and installation of a process monitoring system (DAI) for nuclear inspections at the THORP reprocessing plant in Sellafield (UK)

30983 Maintenance of the process monitoring system at Sellafield

30874 Feasibility study and preliminary design of an unattended monitoring system for the Magnox plutonium store at Sellafield

31906 Implementation of an unattended monitoring system for the Magnox plutonium store at Sellafield

32412 DAI maintenance at THORP

32757 Replacement of loggers at La Hague

32945 R&D on He-3 alternatives

DG HOME 30634 Support to radiological/nuclear security: study on the preparedness of EU27 to face nuclear/radiological threat

31111 Establishment of SeTraC: set-up a (nuclear) Security Training Centre for first responders to detection of nuclear/radiological material at borders

31350 Illicit Trafficking Radiation Detection Assessment Programme (ITRAP+10)

33130 Support to the implementation of the CBRN Action Plan

DG DEVCO 22278 Improvement of the Nuclear Material Accountancy and Control system at the Mayak reprocessing plant (Russia)

30211 TACIS projects:

Task A: Further improvements to NMAC at Mayak reprocessing plant (Russia)

Task B: Establishment of a testing laboratory at VNIIA (Russia)

Task C: Development and introduction of sealing systems at Rosatom (Russia)

Task E: NMAC of spent fuel at Andreeva Bay (Russia)

Task G: Safeguards for RBMK spent fuel storage at Kursk NPP (Russia)

Task H: Fight against illicit trafficking at Ukrainian border crossing stations

Task I: Fight against illicit trafficking at Armenian border crossing stations

Task J: Safeguards for VVER spent fuel storage at Medzamor NPP (Armenia)

31056 Fight against illicit trafficking at Belarus border crossing stations

31581+31804 IfS - Fight against illicit trafficking:

Task MED: Border management in Algeria and Morocco

Task A09: Border monitoring in Afghanistan

Task T09: Border monitoring in Tajikistan

Task U09: Border monitoring in Uzbekistan

Task SEA: Border management in South East Asia

32653 ESF: Management of an Expert Support Facility to implement projects of the Instrument for Stability

32877 Support to CBRN-CoE

32946 IfS projects in SEA and RDC

32948 INSC: Strengthening the Safeguards Capabilities of ABACC

33125 CBRN-CoE 3rd round

DG TRADE 32608 Support on the dual use export control

Indirect Actions (participation to FP6/FP7 projects)

EURITRACK (coordinated by CEA) dealt with the development of a non-intrusive inspection system to detect presence of explosives or other dangerous/illegal materials in cargo containers based on neutron interrogation. JRC lead WP4 consisting in developing the information system.

HAWKEYE (coordinated by ATLIS) dealt with the development and testing of a hyper-spectral thermal infrared analyser to detect clandestine facilities for production of WMD.

SCINTILLA (coordinated by CEA) dealt with the development of an innovative toolkit for detection of RN materials. JRC lead WP4 consisting in evaluation and testing of the instruments developed in the project.

CP-ESFR (coordinated by CEA) aimed to contribute to the development of a European Sodium Fast Reactor within the Generation-IV International Forum (GIF). E08 contributed to the analysis of the proliferation resistance and physical protection (PRPP) issues.

4.3. Mobility and training of researchers

The ESARDA course on nuclear safeguards and non-proliferation is open also to JRC participants. Most of young researchers and newcomers at E08 have followed it and some participants came also from other JRC institutes (IRMM, IPSC) and/or other Commission services (DG ENER, Council).

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

Publications Office