ESARDA
European Safeguards Research & Development Association

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Connector

Issue 4 | Spring 2021

EDITORIAL

by Julie Oddou (ESARDA President)

Dear Reader,

After 2 years of a tremendous Presidency by Willem Janssens and the Joint Research Centre and three editions of the Connector, I am delighted to take over the reins of ESARDA to continue "Advancing Together".

I am also very proud to announce that with Mari Lahti, from POSIVA (Finland), joining the team as new ESARDA Vice-President, and Véronique Berthou our Secretary, we have for the first time a full female trio at the Head of ESARDA. I hope this will encourage young women all over the world to join the community of ESARDA.

Despite the difficult time we are facing all over the world with the pandemic, we managed to overcome distance and to continue exchanging and building up competencies.

In this area, the 19th ESARDA COURSE on

continued on page 2...

INDEX

...continued from front page

Nuclear Safeguards and Non Proliferation organised by the JRC is a wonderful example of agility and adaptation. For the first time, it was an online course, which succeeded in arousing the interest of a high number of attendees all over the world, including from Africa and Asia. Almost 200 participants attended the course. Based on a MoU signed between ESARDA and ENEN and the fact that ENEN received a contract from the European Commission to foster training and education on nuclear safeguards outside Europe, the ENEN colleagues with support of JRC reached out to a number of regions outside Europe. In the outreach for the course, we also benefit from the active participation of another new partner of ESARDA, i.e. The African Commission on Nuclear Energy (AFCONE). The joint effort of AFCONE, ENEN and the JRC contributed to make a big success of this 19th ESARDA Course.

For the future and starting from September 2021, again under contract with ENEN and the Polytechnic University of Milan, funded by the EC and with support from JRC, the first ever full-fledged master course on nuclear safeguards will be organised (mainly virtually) at academic level (for a full duration of 12 months). Link

Homepage of the Nuclear Safeguards master on the Politecnico di Milano website

Virtual group picture of the 19th ESARDA Online Course that took place on 12-16 April 2021

The 2021 Joint INMM/ESARDA Annual Meeting

As announced in the previous editions of the connector, our next annual meeting will be a joint meeting with INMM.

It would have been a pleasure to welcome the ESARDA community in a nice place in France and an even more delight to have the meeting in-person in Vienna together with INMM. Again, due to the pandemic we finally decided to have a full-virtual event.

Nevertheless, it is already a success with around 650 abstracts submitted and we are actively working to its preparation with INMM to offer the best virtual environment for our discussions. With the contribution of many ESARDA participants, including our Working Group Chairs and Vice-Chairs, we are currently working on establishing the program and testing different kind of platforms. The INMM team is utmost professional and efficient and it is a real opportunity to work together in a very close way.

I know that after more than one year of telework, many of you are very disappointed because you would have preferred to meet your colleagues in person. Anyway, we will take advantage of what the virtual version afford to us. There will be more participants from all around the world and more opportunities to exchange with them.

With the continuous improvement of the online tools, I can promise a real interactive conference with many potentials to create discussions in chat rooms with colleagues and online exchanges with posters presenters or panels, in addition to the classical technical sessions.

In order to allow all different time zones to participate at decent hours, we decided to limit the daily time and to expand the duration of the conference (most probably until Wednesday 1st of September).

Registration will be possible very soon and I am expecting many of you!

Editorial Committee news

The Executive Board had a meeting with the Editorial Committee to discuss how to incorporate the Committee in a more institutional role, seeing the nature of activities and duties that are carried out. This change would allow the Editorial Committee to work closely with the hierarchy of the association on the dissemination of information, and drop its role as a working group, which does not reflect its function.

I have the pleasure to announce that issues n.60 and n.61 of the ESARDA Bulletin can now be found in the Scopus indexing database, where citations are collected to provide the publication with an impact factor. I urge all members to cite correctly their work in order to improve the visibility of the journal, allowing it to remain indexed in this important database.

In this Connector fourth issue, you will find news from around the association, working group activity updates, featured articles presenting the TIM Dual-use software, an overview of the upcoming joint annual meeting and the muon tomography for shielded casks project. Furthermore, you will find two technical articles on the following topics: “SLAFKA,” the world’s first blockchain prototype for nuclear safeguards information management, by Cindy Vestergaard, and the ESARDA course student paper entitled “Key characteristics for proliferation-resistant generation IV reactors”, by Ms Boytsova.

Enjoy reading this fourth edition of our Connector!

Julie ODDOU

ESARDA President

news & events

Keeping you up to date with all the latest news of the association and its partners, as well as all the upcoming events in the near future.

NEWS

The ESARDA Course went digital and doubled the attendance!

source: JRC Science Hub ©EU, (16/4/2021).

While last year JRC had to cancel the annual European Safeguards Research and Development Association (ESARDA) training course, this year the event went fully digital and the 19th edition was more successful than ever, with 150 participants from all over the world.

From 2002 to 2019, the in-presence course usually counted 60 participants from Europe. This year, thanks also to the contribution of the European Nuclear Education Network (ENEN) and the cooperation with the African Commission on Nuclear Energy (AFCONE), more participants from outside Europe could join, among which 60 from African nuclear organisations. The online format made the course much more accessible and doubled the participation (fig. 1)

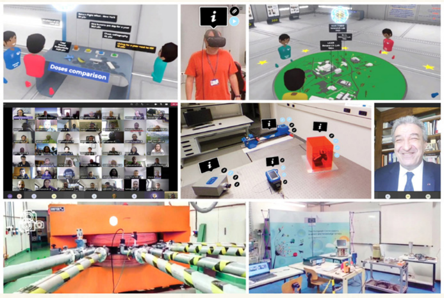


Fig.1 Collage of images from the 19th ESARDA Course that went digital and doubled the attendance!

For this online edition of the course, the organisation team made considerable efforts, together with the lecturers, to convert the entire content, including exercises and visits to the JRC Ispra site nuclear laboratories, into a virtual format. Up to 15 virtual rooms were created for group discussions and practical exercises. And the virtual laboratory tours of the Advanced Safeguards laboratory (AS3ML) – fig. 2 - and of the Ispra Nuclear Laboratories (INS3L) allowed the participants to have a closer look at nuclear safeguards equipment and instruments from their remote locations.

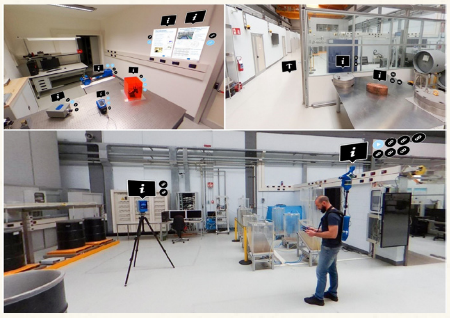


Fig.2 Collage of images from the 19th ESARDA Course that went digital and doubled the attendance!

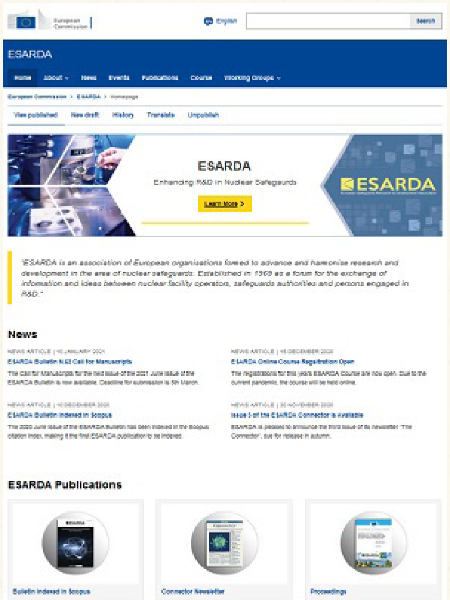
Editorial Committee updates

Following the acceptance of the ESARDA Bulletin in Scopus, in January the 61st Bulletin Issue was loaded into the indexation database. To view the ESARDA Bulletin simply visit Scopus and search by ISSN for 1977-5296. As you are aware, Scopus provides the citation for each paper included in the database. We urge all authors to cite papers correctly in order to help the publication increase its impact factor.

The Editorial Committee has also issued a new Publication Policy, in order to assist all potential authors on what is required from them. The publication policy was submitted by the Editorial Committee to the Executive board, who approved it in February. To read it please follow this link.

New ESARDA website

The existing ESARDA website was launched back in 2012, and the time has come to redevlop it on a new platform. The new website is based on the Drupal content management system, and is hosted on the European Commission servers. This new platform will greatly reduce the chances of being attacked, and also provides new features, which will no doubt increase the user experience. The expected launch date is the 17th May 2021, and no changes are required from the users, as the wesbite will keep the existing URL.



Preview of the new ESARDA website

MUTOMCA project announced

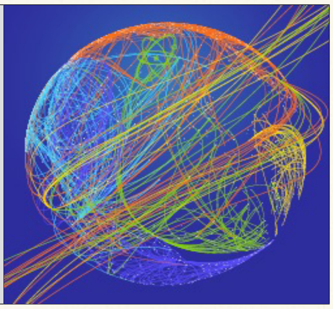
The recently started MUTOMCA project investigates muon tomography as a method to detect the diversion of spent fuel assemblies in shielded casks for safeguards re-verification purposes. This project is an international collaboration among the National Institute for Nuclear Physics (INFN; Italy), the Jülich Research Centre (FZJ; Germany), BGZ Company for Interim Storage (BGZ Gesellschaft für Zwischenlagerung mbH (BGZ; Germany) and the European Atomic Energy Community (EURATOM).

For more information read on in the featured articles section.

Call for Papers Released for ESARDA Bulletin Special Issue on Data Analytics for Safeguards and Non-Proliferation

Recent advances in data analytics have the potential to make significant contributions to the fields of nuclear safeguards and non-proliferation. ESARDA has recognized this potential, and specifically called out topics relevant to data analytics including business intelligence and artificial intelligence in the 2019 World Café activity from the 42nd Annual Meeting held in Stresa, Italy, in May 2019. Even before the calls for action resulting from the World Café, the ESARDA Verification Technologies and Methodologies (VTM) working group has taken active interest in further exploring data analytics applications for safeguards and non-proliferation, including several topical sessions focused on data analytics research being conducted within our community, a new recurring segment to our working group meetings called "what is…" which will offer explanations of methods being discussed for safeguards, and ongoing planning for a data analytics challenge. In order to provide a single forum for the latest research and development on data analytics for nuclear safeguards and non-proliferation, the VTM working group is organizing a special topical issue of the ESARDA Bulletin on data analytics. The special issue will feature manuscripts describing research and development of data analytics methods applied to safeguards and non-proliferation data or use cases.
Authors interested in submitting should follow the submission forms and paper guidelines for the Bulletin's website for all submissions. Authors are requested to submit abstracts to the Bulletin editors by September 1, 2021 as an intent to submit a full manuscript, and full manuscripts are due to the editors September 30, 2021. Publication decisions will be provided to authors after peer review, with final manuscripts are due November 10, 2021. Questions regarding the special issue topics or content should contact the VTM Chair and special issue guest editor, Zoe Gastelum.

EVENTS

2021 June 21-25	21st - 25th June 2021 **ANIMMA 2021** Clarion Congress Hotel Prague, Czech Republic The 7th International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications. ANIMMA 2021 is the seventh of a series of conferences devoted to endorsing and promoting scientific and technical activities based on nuclear instrumentation and measurements. [Read more]	
2021 August 21-26	21st - 26th August 2021 **INMM & ESARDA Joint Annual Meetings** Virtual Meeting The INMM and ESARDA joint annual meetings provides a unique opportunity for research organisations, safeguards authorities and nuclear plant operators to exchange information on new aspects of international safeguards and non-proliferation, as well as recent developments in nuclear safeguards and non-proliferation related research activities and their implications for the safeguards community. [Read more]	

working group reports

This section of the Connector has the objective to inform the ESARDA Community about the latest undertaking of the Working Groups' activities during the last six months. Each Working Group Chair has been invited to provide a brief article describing their findings in their fields of interest.

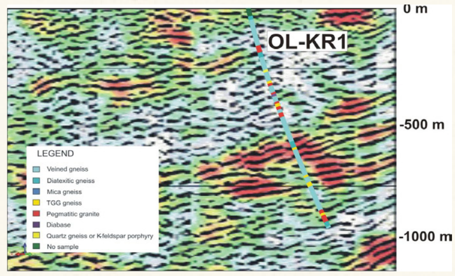
JOINT WORKING GROUP MEETING BETWEEN CONTAINMENT AND SURVEILLANCE (C/S) & FINAL DISPOSAL (FD)

by Katharina Aymanns,
(C/S Working Group Chair),
Klaas van der Meer
(FD Working Group Chair),
Mentor Murtezi
(FD Working Group Vice-Chair)

This joint Working Group meeting intended to bring together the C&S and Final Disposal specialists, as it is clear that safeguarding a geological repository will rely heavily on C&S measures. It should be said that there is a good overlap of people between the two Working Groups.
About 60 people participated in this joint session.

Four presentations were given in this joint meeting. Mentor Murtezi from DG ENER started with a presentation on the safeguards approach of a geological repository. Main elements that he discussed were the need for Continuity of Knowledge and how flow monitoring could be used for that. An important question was also where we should stop monitoring the flow and just make sure that nothing goes out a defined area, i.e. monitor the entrances of that area. Remote sensing, seismic monitoring and Ar measurements could all serve as part of the solution.

Olli Okko (STUK) presented some ideas for safeguardig geological repositories, keeping in mind the safety principles of such a repository. These are based on passive safety and imply no intervention once the repository is closed. As an illustration of the difficulty to monitor the repository from a distance, he showed results of seismic data in the figure below, which is hard to interpret, even by specialists. Three take away messages were given: the DIQ and DIV should be revisited as needs and details are not well defined; for CoK it should be indicated which records should be kept, how long and how secure; C&S on disposal canisters was considered as not possible.
Jan Olov Stahl (SKB) presented the state-of-



Picture showing the complexity of interpreting seismic data
Source: STUK

the-art of the design of the repository facilities in Sweden. It was a comprehensive overview of the encapsulation plant, the transport cask to be used, the geological repository and required spent fuel characterization. Identification of disposal canisters and sealing of transport casks was discussed for the sake of Continuity of Knowledge.

Sanna Mustonen and Mari Lahti (POSIVA) pesented the state-of-the-art of the repository project in Finland. An impressive progress was shown, including pictures of the conditioning plant under construction and to be commissioned in 2022. Work on the geological repository is continuing and the first disposition tunnels are planned to be constructed next year 2021.

Next meeting is envisaged to be a joint C&S-NDA-FD meeting in March 2021. The format will be most probably a web-meeting, similar like this one.

STANDARDS AND TECHNIQUES FOR DESTRUCTIVE ANALYSIS WORKING GROUP (DA)

by Evelyn Zuleger
(DA Working Group Vice-Chair)

The task of the ESARDA Working Group on Standards and Techniques for Destructive Analysis (WG DA) is to provide the Safeguards Community with an expert advice on reference standards, procedures and analytical techniques for the analysis of a wide range of safeguards samples. Since the last DA WG meeting held within the 42nd ESARDA annual meeting in November 2020 the IAEA has started the revision of the International Target Values (ITV) for measurement uncertainties in safeguarding nuclear materials and many members of the working group have accepted to support the IAEA in this task. The Kick-off meeting for the DA related ITV tables has been held on March, 22 with 43 participants. Four subgroups, where two groups are covering a set of analysis techniques, and one sampling and sample preparation, as well as one group for Asian contributors have established with the aim of finalizing the review in early June 2021.

In addition, the EC-JRC, in cooperation with the CETAMA (CEA) and the IAEA, has started the procedure to prepare a new U-233 and

Picture showing the convergence of two tunnels
Source: POSIVA

a new mixed U-233/Pu-242 spike certified reference materials (CRMs) for destructive analysis. These spikes will be certified for the amount content and isotope amount ratios of U and Pu, applicable in isotope dilution mass spectrometry (IDMS) analysis. The preparation of these materials is part of the support to the safeguards measurement community to ensure a continuous supply of quality control tools.

The next ESARDA WG DA meeting will be held virtually together with the INMM counterpart at the Joint INMM/ESARDA Annual Meeting in August, 21 – 26, 2021 in Vienna. Details and an agenda will be provided in the near future.

EXPORT CONTROL WORKING GROUP (EXP)

by Christos Charatsis
(EXP Working Group Chair)
Johan Evers
(EXP Working Group Vice-Chair)

Follow-up activities to the 13th ESARDA EXP-WG

Following the fruitful discussions in the context of the 13th ESARDA EXP-WG meeting and ESARDA's 42nd Annual meeting, in November 2020, the Chair of the EXP-WG, C. Charatsis and the new Chair of the VTM-GW Z. Gastelum continued discussions on identifying concrete topics of collaboration between the two Groups. In parallel, the closer contacts established with the chairs of the INMM's export control WG and further exchanges among experts from the EC –JRC and US laboratories, provided the impetus to pursue a joint project in view also of the forthcoming joint INMM- ESARDA Annual meeting, in August 2021. The outcome of these exchanges was the submittal to the annual meeting committee of a joint paper and the proposal for a special panel discussion. Both initiatives will highlight the interfaces of export controls and safeguards with a special focus on the complementarity of data, analysis, and goals of relevance to export control and safeguards experts.

Establishing best practice to prevent misuse of academic knowledge for proliferation purposes

The chair and vice-chair of the ESARDA EXP-WG, C. Charatsis and J. Evers contributed to an online international conference organised by the King's College London with support from the UK's Foreign, Commonwealth & Development Office. The workshop brought together about 120 representatives per day from European universities and governments including participation from US, Canada, Japan and Australia with the aim to discuss best practice to prevent the misuse of academic knowledge for proliferation purposes.

The three day discussions (29-31 March) exposed participants to a range of existing legislative efforts and guidance that governments have in place concerning the transfer of sensitive technology and explored the different standards expected of universities in delivering comprehensive compliance.

The EXP-WG chair led a breakout discussion on the various security risks that can emerge in the course of transnational research collaborations. Some of the issues touched upon included: the tensions shaping the international environment (e.g. civil/military integration vs. strategic autonomy, openness vs. data/info protection); the significance of an effective risk assessment embedded in the institutional policies and procedures of research organisations; the challenges faced by researchers and administrative staff when complying with export control obligations; the net of instruments (top-down and self-governance measures) that can operate in a synergetic manner with a view to monitoring sensitive research and last, the key concept of security literacy for students and researchers. In the same panel, Renata P. Schaeffer, the Head of Public International Partnerships at the University of Cambridge discussed Cambridge's approach and experience in promoting compliance and a security culture within large and decentralised organisations such as Cambridge.
The vice-chair of the EXP-WG led a breakout discussion on the challenges related to aligning regulatory export compliance objectives and research realities in the area of publications. While the act of publishing is only one of the scenarios where export controls may come into place, it attracts quite some attention as a disproportionate bureaucratic burden, undermining international research cooperation, as well as jeopardising institutional autonomy and academic freedom. The discussion highlighted the tension between export controls, open science and public research funding, the lack of awareness on the potential misuse of research results for proliferation purposes and how to apply classic licence modalities (such as stated consignee or end-user) to a publication. In the same session Mr. Christian Kachel (Fraunhofer-Gesellschaft, Germany) elaborated on the export control issues regarding to the filing and publishing of patent applications and on the role that patent offices play in the treatment of patent applications in the US and EU export control systems.

The conclusions of the conference referred inter alia to the need to develop additional guidance and tools preferably at the EU level to assist research organisations in their effort to mitigate the different types of risk and comply with the an ever growing set of laws, regulations and ethical imperatives requiring enhanced due diligence procedures by research institutions. Coordinating different policy instruments, developing an EU e-learning course for export control matters and investing further in data mining tools such as TIM DU that can be useful for targeting risk assessment and awareness raising efforts were among the proposals suggested by University representatives.

VERIFICATION TECHNOLOGIES AND METHODOLOGIES WORKING GROUP (VTM)

by Zoe Gastelum
(VTM Working Group Chair)

The Verification Technologies and Methodologies (VTM) working group is a horizontal working group which aims to evaluate the potential technical opportunities and challenges of new or new-use technologies and methodologies to the verification of nuclear safeguards and other non-proliferation agreements.

Since our last working group meeting, the VTM Working Group has undergone a change in leadership. We thank our former Chair, Keir Allen from the Atomic Weapons Establishment in the UK, for his over two years of service as chair. Under Keir's leadership, the working group began in-depth focuses on timely topics including potential future arms control verification regimes in the Democratic People's Republic of Korea, and the growing interest in data analytics. We wish Keir all the best and hope for his continued engagement in the working group. Zoe Gastelum from Sandia National Laboratories in the USA has taken over the chair, after serving as Keir's Vice Chair the past two and a half years, and Cristina Versino from the Joint Research Centre in Italy has been confirmed as the new Vice Chair.

Following a productive joint meeting of the VTM working group and the ESARDA Export Controls (EXC) working group in November 2020, the working groups collaborated closely with the Institute of Nuclear Materials Management Export Controls working group to organize a joint session for the ESARDA/INMM joint virtual annual meeting in August on the interdependencies and complements of export controls data for safeguards, which will feature a discussion by invited subject matter experts. The joint session will be announced as part of the annual meeting program later this spring.
On March 19, 2021, the VTM working group met virtually for over three hours, taking advantage of the reduced time difference between the United States and European countries resulting from different dates to change clocks to summer-time. The agenda opened with a new recurring segment on "what is…?" in which members of the working group will describe the details, opportunities, and challenges of new or increasingly visible technologies for nuclear safeguards and non-proliferation challenges. The first "what is…?" segment was focused on business intelligence, in response to interest expressed in the World Café and through remarks at recent ESARDA events. Cristina Versino described what business intelligence means, what its capabilities are, what data is suitable for use in business intelligence, and conducted a live demonstration of her preferred business intelligence platform, Tableau, to analyze strategic trade data. Following her explanation and demonstration, three panelists offered short interventions in which they specifically discussed how they use business intelligence in their daily work in nuclear safeguards and nonproliferation. The panel discussion included Elena Marinova from the IAEA who discussed the experience of the International Atomic Energy Agency Department of Safeguards' State Factors section using business intelligence for analysis and visualization of trade statistics to support assessment of states' general industrial capability, and showed the group an anonymized visualization of the Nuclear-Related Industrial Capability Map used in the section. The panel also included Elena Stringa from the Joint Research Centre, who discussed her use of business intelligence to support assessments of denied exports for the European Commission's compliance monitoring. The panel closed with a discussion from Kamshat Saginbekova from Liege University who described the challenges she encountered while trying to download strategic trade data to assess dual-use technologies in Central Asian countries. In addition to the limitations of the data itself, she described the lengthy time requirements in order to download all relevant data from the BACI database, and potential for errors.

The working group meeting also included two topical research updates from working group members. In the first research update, Olli Okko from STUK described an update on the potential to use seismic monitoring, including over 100 years of historical observations and records, to support safeguards at the Olkiluoto Repository. He also described challenges from unknown features, and several recent studies to support tunnel detection and characterization.

The second research update was from Zoe Gastelum, in which she described how the limitations of available safeguards-relevant imagery posed challenges for the development of deep learning computer vision models, and how synthetically generated images from 3D computer models might be able to support model development. She described how synthetic imagery has been successfully used to train models in other domains and provided examples of synthetic images relevant to nuclear safeguards.

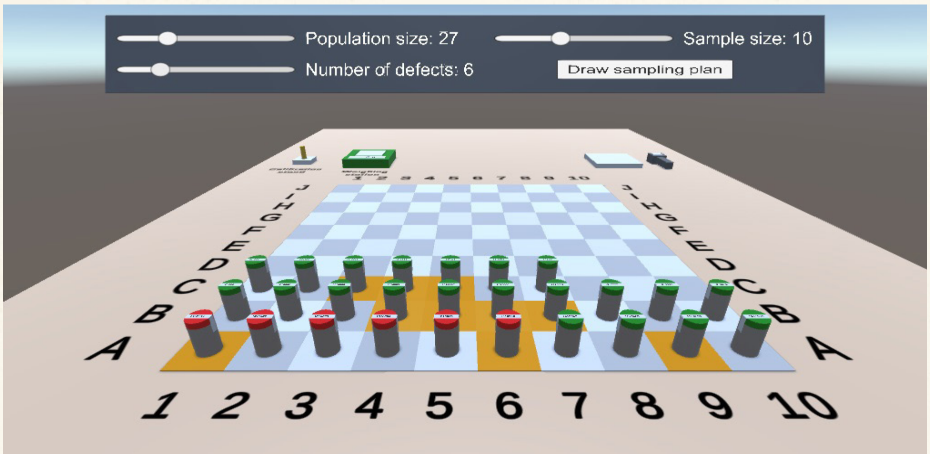
TRAINING AND KNOWLEDGE MANAGEMENT WORKING GROUP (TKM)

by Thomas Krieger
(TKM Working Group Chair), and
Riccardo Rossa
(TKM Working Group Vice-Chair)

The IAEA has launched the task "Online Course Development Consultation", in which – inter alia – online training courses will be developed to help the Safeguards Department to provide knowledge and skills to Member States when in-person training is not possible (e.g., during times of restricted travel and in-person meetings) or to complement the portfolio of in-person courses. In this context Riccardo Rossa (SCK-CEN, Mol, Belgium) and Thomas Krieger (Forschungszentrum Jülich GmbH, Germany) are developing a virtual reality (VR) software that will complement a training course on sampling plans. The main idea is to have a hands-on introduction into the practice and theory of sampling plans.

The VR software (see Figure) will contain a material balance area where participants can carry out several exercises. The population size, the number of defective items, and the number of selected items, i.e., the sample size, can be selected interactively by the participants. An electronic scale is also included in the VR software, so that the participants can verify the mass of the items compared to the operator declaration.

In the Figure in a population with 27 items, 6 of them – indicated by a red lid – are defective which means here that they contain less material than declared. The 10 orange-coloured fields show the items selected for verification. Because this selection is random, pushing the button "drawing sampling plan" again will lead to a different set of 10 orange-coloured fields. In the exercises the trainee will – among other things – 1) estimate the probability that a certain number of defective items is in the sample, will 2) explore the properties of a multiplicative error model using the electronic scale, and will



Picture showing screengrab of the VR Softwares

3) estimate the detection probability, i.e., the probability that at least one defective item is identified (using the scale and a threshold) as defective.

An announcement regarding the "Specializing Master program on Nuclear Safeguards" (https://www.nuclearsafeguards.polimi.it/) was sent out to all ESARDA WG Chairs, and they were asked to distribute the information inside their WG and to anyone else who is interested in a Safeguards master. This master programme will start in October 2021, and is organized by Politecnico di Milano and the European Nuclear Education Network (ENEN), in collaboration with European Joint Research Centers (EU JRC), Academic institution participating in the ENEN, and International organizations (e.g. IAEA). The master course gives the opportunity to train and develop the competences of employees in order to enhance the efficiency of their actions in the field of nuclear safeguards and support the continuous development of a professional, competent and motivated workforce. Some members of the TKM WG are involved in the development of a module in this master program. Currently the structure of the modules are defined. In the next step it will be decided which material will be taught in video sessions, webinars and activities.

An information was sent out to all ESARDA WG Chairs drawing their attention to an IAEA "Self-study Online Course on Safeguards". This course has been designed by the IAEA to provide an overview of and introduction to Safeguards for Member States as well as others interested in learning more about Safeguards. It is an estimated three hour commitment, and successful completion enables the participant to obtain a certificate of completion. The TKM WG has already received feedback from the course participants regarding the content and structure of the course. The feedbacks will be collected and then provided to the IAEA in a timely manner.

A short virtual kick-off meeting on ''Remote Hands-On Technical Training'' was held. Because of the pandemic context and the respective travel restrictions, no hands-on training can be provided to participants, e.g., in the ESARDA Course. Therefore, there is an urgent need to develop alternatives. For the next meeting it is planned to share experiences about combining hands-on activities with remote training, and to start a survey of existing technologies.

STANDARDS AND TECHNIQUES FOR NON-DESTRUCTIVE ANALYSIS WORKING GROUP (NDA)

by Hamid Tagziria
(NDA Working Group Chair)

As was reported to the ESARDA communities and members of the NDA working group (WG) we have the great pleasure in welcoming to the WG committee three excellent and well qualified vice-chairs namely:

a. Darius Ancius, EC-DG-ENER, Luxemburg
b. William (Bill) Geist, DOE-LANL, USA
c. Ramkumar Venkataraman , DOE-ORNL. USA

We have had a few meetings and we look forward to establishing the framework for activities and further progress in the next two years. It is safe to assert that Covid-19 situation over the year has affected adversely laboratory and off-site measurement campaigns in general and the work of the NDA WG in view of the nature of its activities as one would expect. However, developments and progress on a number of topics well reported and presented at the 42nd ESARDA annual meetings in November continued in very satisfactory way. This is seen in the large number and quality of abstracts submitted to the forthcoming INMM-ESARDA symposium by members of the NDA WG.

One of the main objectives of the NDA WG is to provide the Safeguards Community with expert advice on NDA techniques, procedure on standards and reference materials and on the performance of NDA methods. To that effect the NDA WG has been brainstorming and discussing the challenges faced by users and operators and the potential solutions that can be applied, some of which were presented at the symposium, are being suggested and this endeavor will gain in importance and momentum in the coming months.
Many of the NDA WG members including the chair and vice chairs have been heavily involved in various groups and activities such as:

a) The revision and updating of the International Target Values (ITV2020) which, in essence, provides a reference system for a sound evaluation and comparison of the qualities of both the measurements carried out by inspectors during verification and of the declarations by the facility operators. See presentation by Claude Norman at the 42nd ESRADA symposium in November 2020. Since then a number of sub working groups have been formed to which NDA practitioners and WG members are actively participating and contributing. Good progress has been made.
b) The preparation of the forthcoming INMM –ESARDA symposium

- Program formulation and design
- Review of abstracts

- Submission of many abstracts by many NDA WG members
- Potential NDA topics for being included in the INMM-ESARDA Symposium were discussed by the Chair and Vice-chairs
    i. Availability of AmLi sources;
    ii. Replacement of AmLi sources (Cf-252, AmBe, DD generators, etc);
    iii. New measurement techniques such as the IAEA's FNCL (Fast Neutron Collar), European Fast NeutronCounter, …
    iv. Passive measurement tech niques, such as FNPC (Fast Neutron Passive Collar), applied nuclear material typically assayed with active methods.
    v. Safeguards application of medium resolution gamma spectrometers (MRGS)

IMPLEMENTATION OF SAFEGUARDS WORKING GROUP (IS)

by Walid M'Rad Dali
(IS Working Group Chair)
by Marko Hämäläinen
(IS Working Group Vice-Chair)

The Implementation of Safeguards Working Group (IS WG) is a horizontal issues working group of ESARDA. Its objective is to provide the Safeguards Community with proposals and expert advice on the implementation of safeguards concepts, methodologies and approaches aiming at enhancing the effectiveness and efficiency of safeguards on all levels. This WG is also a forum for exchange of information and experiences on safeguards implementation.

The IS WG normally organises at least twice a year a two-days meeting. Like in 2020, due to the COVID-19 pandemic which is unfortunately still ongoing this year, the WG activities were delayed and the WG has not had the opportunity yet to meet this year. The next meeting of the group is supposed to be held through a videoconference format in the margins of the next INMM and ESARDA joint annual meeting in Augustus 2021. Considering the success of the 2020 FD/C&S/IS trilateral meeting, the idea to organise a second trilateral meeting with these WGs during this next joint event is present. Also a second IS WG meeting could be organised at the end of the year, hopefully in a classroom mode depending on the evolution of the pandemic.

In spite of limitations related to the pandemic, the WG moved forward in the two main themes the group is involved in since 2019, namely the "Inspection regime in ESARDA countries" theme and the "Safeguards by Design in ESARDA countries" theme. The group gathered for these two themes sufficient answers to the questionnaires it delivered in 2020 to process the provided information and to draw first outputs. The next joint INMM and ESARDA annual meeting will be the opportunity for the group to present its first results.

It is also worth mentioning that the group was involved in the preparation and the conduct of a STUK-FANC joint workshop relating to the Safeguards by Design in April 2021. During this event organised in a virtual format, members from Euratom and the International Atomic Energy Agency did also take part to the discussions and exchanges.

About the coordinating role of the IS WG in the drafting process of a new State level chapter, it is worth mentioning that all the subchapters needed were delivered. The group is thus currently working on the merging of these subchapters to form a coherent and consistent set that will be a part of the next version of the ESARDA Syllabus.

Finally, the WG is involved in the preparation of the August 2021 event. As an example, it has been involved in the review process of a certain number of abstracts submitted and in the sessions and planning preparation. This work, conducted with the INMM is currently still ongoing.

featured articles

This section presents prominent articles on the latest news and topics of interest in the safeguards community

TIM DUAL-USE: A TOOL TO TRACK POSSIBLE DUAL-USE RELEVANCE OF RESEARCH AND INNOVATION RESULTS

source: JRC Science Hub ©EU, 2021
contact: Filippo Sevini
(European Commission -
Joint Research Centre)

Dual-use goods and export controls

Because they can also be used to produce or spread nuclear and other weapons of mass destruction, so-called dual-use goods cannot be freely exchanged: in the European Union, they are subject to export controls under the EC Dual use regulation 428/2009. Specific materials, electronic components, mechanical systems, sensors, or telecommunication equipment, for example, are listed under the EU dual-use export control list.

Export controls, however, do not apply only to goods but also to knowledge and data contained in research results.

Tools for Innovation Monitoring, TIM Dual-Use is the tool developed at the JRC to navigate research results and identify those that can potentially represent a threat for the proliferation of weapons of mass destruction.

TIM

JRC Text Mining experts have developed TIM Technology as a web-based platform to interrogate a regularly updated database of over 70 million documents, made of scientific abstracts, patents from all over the world and EU-funded projects. The user can visualise the results of the queries in detailed lists and graphics, including powerful visualisations of knowledge maps and cooperation networks.

TIM Technology has been developed to support the design, implementation and monitoring of European research and innovation policies.

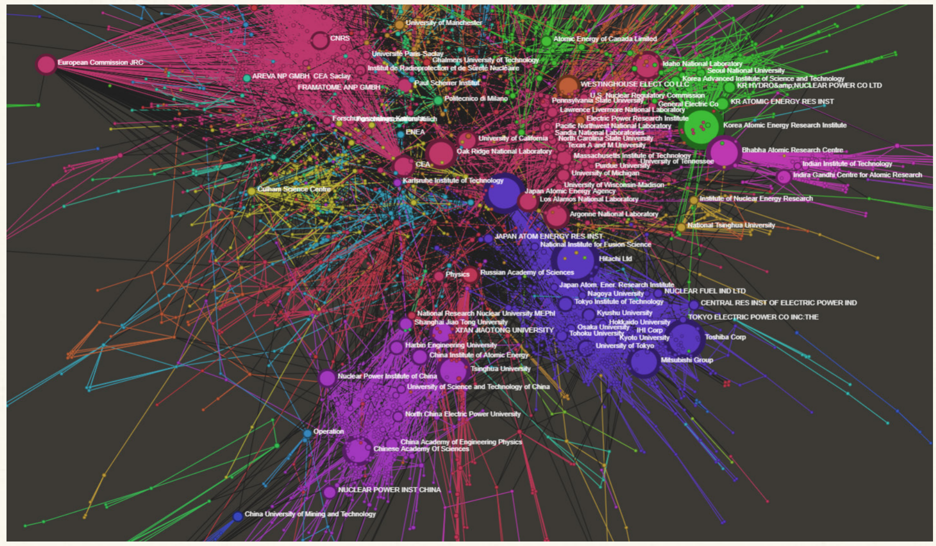


Figure 1: Main nuclear organisations per publications and patents in 1996-2020, and their connections – source: JRC with TIM DU, ©EU, 2021

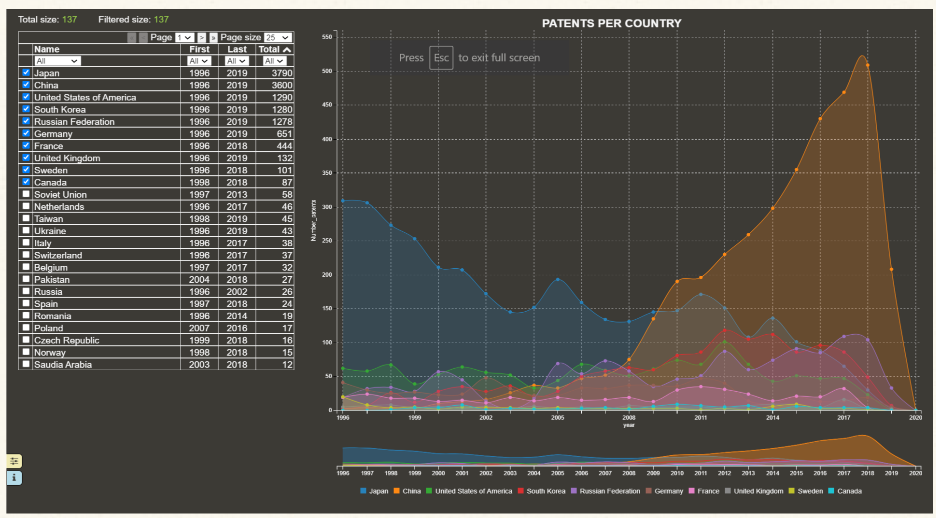


Figure 2: Evolution of nuclear-related patents per country (1996-2019)
source: JRC with TIM DU, ©EU, 2021

TIM Dual-Use

With the cooperation of JRC Nuclear Security experts and Liège University, TIM has been customised for dual-use related queries associated with each of the 10 categories of items listed under EU dual-use export controls, as well as emerging technologies of possible concern. Many features allow the user to navigate through the data to extract knowledge. As examples, TIM Dual-Use can produce maps of the main nuclear organisations per publications and patents and their collaboration network (fig. 1) or the evolution of nuclear related patents per country in the years 1996-2019 (fig. 2).

Initially developed for the Directorate General for Development and Cooperation and the Directorate General for Trade, TIM Dual-Use can be exploited in a wider variety of applications, such as contributing to identify collaboration networks around research of dual-use concern, or targeting awareness-raising activities to improve internal compliance and secure technology transfers.

TIM Dual-Use is web-based and accessible to all.

Visit the TIM Dual-Use website here.

THE INAUGURAL 2021 JOINT INMM-ESARDA ANNUAL MEETING - ADVANCING TOGETHER: INNOVATION AND RESILIENCE IN NUCLEAR MATERIALS MANAGEMENT

by Elizabeth Hogan
(INMM Meeting Coordinator) and
Carrie Mathews
(INMM Technical Program Committee Chair)

Program details are coming together for this year's annual meeting - the first to be held as a partnership between the Institute of Nuclear Materials Management (INMM) and ESARDA.

Originally scheduled to be held this August in Vienna, the meeting will now be held online due to continued concerns for the health and safety of all members, industry partners, volunteer leaders, staff, and other stakeholders during the COVID-19 pandemic. The virtual event will be hosted on a modern platform designed to replicate the experience of an in-person conference as closely as possible, delivering functionality for live presentations, video chatting, gamification, exhibitor booths, networking and collecting materials in each participant's 'briefcase'.

The meeting will take place over two weeks in late August – early September, with shorter sessions each day to accommodate the international audience. The platform will be accessible to presenters and attendees from around the globe a couple of weeks before the meeting begins, to allow everyone to familiarize themselves with the program, create their own calendar of sessions to attend, and personalize their profiles.

With more than 600 abstracts received, the Technical Program will reflect the diverse scope of the two organizations, focusing on all aspects of nuclear materials management – from nuclear safeguards, nonproliferation and nuclear security, to advancements in the nuclear fuel cycle, cyber and emerging technologies, and the growing contributions of nuclear techniques to sustainable development around the world. Some special events and workshops will also be offered over the course of the meeting.

The content, including plenary speakers, panels, oral and poster presentations, will be delivered via the robust and user-friendly platform, with options that elevate it far beyond a standard webinar, structured to offer insight into audience perceptions, concerns and interests, and facilitate audience-speaker interaction, or moderated Q&A sessions by session chairs. All content will be recorded and retained online.

The 2021 INMM/ESARDA Joint Meeting theme acknowledges the importance of cooperation and community in advancing the responsible use of nuclear material, and this virtual program will allow us to share what we've learned about innovation and resilience during this past year.

In early May, look for the detailed program on the 2021 meeting website, along with registration and exhibitor opportunities. We look forward to seeing you there!

For more information:
https://inmm.org/mpage/INMMESARDA2021

MUTOMCA PROJECT (MUON TOMOGRAPHY FOR SHIELDED CASKS)

by Katharina Aymanns
(Forschungszentrum Jülich GmbH)

Investigation of muon tomography for re-verification of spent fuel casks

In the next decades, the back end of the nuclear fuel cycle will attract more and more attention by the safeguards community. Due to the shutdown of numerous nuclear reactors throughout the EU the amount of dry-stored spent fuel is increasing. Keeping the continuity of knowledge (CoK) of intermediately stored spent fuel is a key element of safeguards. Taking into account its long storage times for several decades, there is a non-negligible risk of loss of CoK. Moreover, presently there is no adequate non-destructive (re)-verification method for casks available. Therefore, the development of a potentially suitable technology for re-verification and an investigation of its application in the field is required.

Muon tomography detector (courtesy: INFN)

The scope of the MUTOMCA project is to investigate muon tomography as a method to detect the diversion of spent fuel assemblies in shielded casks for safeguards re-verification purposes. It implies the construction of a muon detector capable of showing the interior of the shielded casks including the spent fuel assemblies in a very precise tomographic image while operating from the outside.

This project is an international collaboration among the National Institute for Nuclear Physics (INFN;Italy), the Jülich Research Center (FZJ;Germany), BGZ Company for Interim Storage (BGZ Gesellschaft für Zwischenlagerung mbH (BGZ; Germany) and the European Atomic Energy Community (EURATOM).

technical articles

Technical articles covering the latest findings of our community of experts on fundamental issues

SLAFKA: ONE YEAR ON

by Cindy Vestergaard
(Stimson, USA)

On March 10, 2020, "SLAFKA," the world's first blockchain prototype for nuclear safeguards information management, was launched in Helsinki, Finland. A joint project between Finland's Radiation and Nuclear Safety Authority (STUK), the Stimson Center's Blockchain in Practice program and the University of New South Wales (UNSW), the prototype is the first developed for a nuclear regulator and is based on Finland's system of accounting and control which uses a centrally stored database called SAFKA. The name, "SLAFKA" therefore emerges from a "shared ledger SAFKA."

SLAFKA demonstrated that a distributed ledger technology can handle safeguards data and address current inefficiencies in safeguards information management.

1 What is DLT

Unlike a centralised database which exists in a fixed location and has a single point of failure, a distributed ledger resides amongst multiple participants across many locations. Distributed ledger technology (DLT) is a distributed record in which transactions are stored in a permanent, immutable way with cryptographic techniques, enhancing transaction transparency and validation while providing data privacy among all parties. Data embedded on the chain is extremely difficult to manipulate, allowing stakeholders to interact in a trusted environment.

More commonly referred to as "blockchain," the technology has been considered over-hyped on the one hand and a revolutionary innovation on the other[1]. As corporations and consortiums are adopting the technology, there is a growing understanding that DLT goes beyond cryptocurrencies, such as Bitcoin, to provide a shared, secure and immutable records management system that stretches across an ecosystem. Major players, from Walmart[2] to Volvo[3] to Louis Vuitton[4], have not only experimented, but adopted DLT as an integrated layer in their global operations.

Although open, public blockchains - the technology that underpins cryptocurrencies - are more widely known; it is the private permissioned, or enterprise, platforms that are more widespread. From tracking food to high-value minerals and luxury goods, freight logistics and pharmaceuticals, these permissioned platforms are restricted to known and authorized participants and do not disrupt governance structures. Instead, they use the technology for distributing transparency across global operations, securing and scaling digitized information and tracking supply chains. These platforms work best in already highly governed ecosystems and are generating research around the value of DLT for global business operations and trade. They are also attracting attention within the nuclear safeguards community – governments, industry, and academia – where verifying compliance with international obligations requires a high level of data integrity and trust.

Transactions on a DLT platform can be easily traced as they are time-stamped and given a cryptographic signature or a "hash," essentially a digital fingerprint that interlinks transactions as they are appended to the ledger. Each transaction and group of transactions (or blocks) stores the hash of its predecessor and any attempts to alter a transaction are rejected as incompatible with rest of the chain and all participants alerted. Hashing along with data replication across nodes gives DLT its immutability.

Figure 1 depicts immutability where if an actor tries to modify Transaction A to Transaction A' then Block 2 would be stored as #A'BCD which would no longer correspond to the previous hash stored in Block 3.

2 Developing SLAFKA

SLAFKA is based on Finland's SSAC and is made up of two kinds of participants as outlined in Figure 2: three operators (FTPower, PVO, and DGROrg) and three regulators (FinREG, RegionREG, and WorldREG). FTPower and PVO represent nuclear power plants, and DGROrg represents the deep geological repository. For the regulators, FinREG represents the national regulator, RegionREG the regional authority (such as Euratom), and WorldREG the international regulator (with a similar function to the IAEA).

In line with confidentiality rules for nuclear safeguards data, SLAFKA was built on Hyperledger Fabric, a permissioned DLT platform to: (1) act as a realistic test on the feasibility of blockchain for safeguards, and (2) provide a genuine educational experience for users to interact with a real DLT platform for nucle-

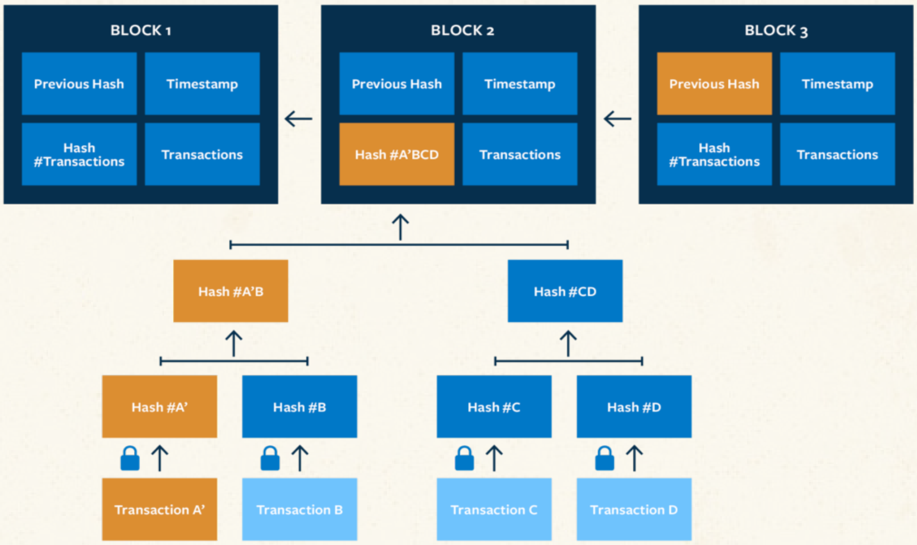


Figure 1: Immutability[5]

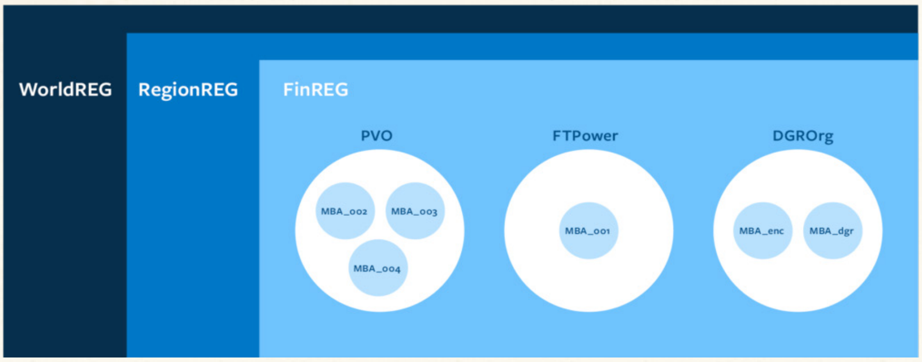


Figure 2: SLAFKA Ecosystem

ar materials accounting. SLAFKA's access controls allow holders of nuclear material (FTPower, PVO, and DGROrg) to input and view their own inventories (not the inventories of other holders), and regulators have visibility of operator inventories. RegionREG and FinREG have permission to query and show provenance of all batches in their jurisdiction (in practice, this means all SLAFKA batches, because it is based on a single State). In addition, RegionREG and FinREG are permissioned to verify batches through an inspection, which nuclear material holders do not have. The third regulator, WorldREG, has the same permissions as other regulators except that WorldREG's Query transaction does not extend down to accessing Key Measurement Points (KMPs). This was purposeful to demonstrate how access controls can differ and how regulators further up the regulatory hierarchy do not necessarily need to have the greatest authority in SLAFKA.

STUK's motivation for testing the potential of DLT for safeguards information management was based on a variety of factors:[6]

- Finland's current software for SAFKA generally operates smoothly; but its ability to validate data is less dependable
- Operators have noted software errors and inefficiencies related to mistakes/corrections in SAFKA
- Matching of domestic shipments to receipts are currently manually run and only works if the receipt and shipment are domestic
- While STUK receives reports from operators via secure lines to STUK (without cryptography) and stored and rendered unchangeable in STUK's digital document handling system, operators report to the European Commission over unencrypted email which is less secure. The transfer of data to STUK and Euratom therefore becomes increasingly vulnerable to cyberattacks as new cyber threats emerge.
- The inspectorates (STUK, EC and IAEA) do not compare the nuclear material balances in their databases and errors may go unnoticed over extended periods of time
- In constructing the world's first deep geological repository, one of the biggest challenges is establishing confidence that the inventory below ground is the same as what is reflected in the records above ground. As noted by STUK, safeguarding spent fuel underground presents new challenges where "the significance of data integrity is immense."[7]

3 Safeguards Powered by Blockchain

SLAFKA demonstrated that DLT can provide solutions to many of the inefficiencies and challenges noted above. It demonstrated that DLT can handle nuclear material accounting information to meet reporting requirements (such as ICRs, PILs, and MBRs[8]) under Commission Safeguards Regulation No 302/2005. SLAFKA transactions include domestic and international shipment/receipt, remeasurements, nuclear loss, nuclear production, change attributes, rebatching, underground disposal, and verification by the regulator. DLT platforms will therefore not change what safeguards information is reported and will not replace the need for inspectors to verify physical inventories against information recorded on the ledger[9]. Moreover, inspectors can monitor changes to inventories as they are entered instead of waiting 30 to 60 days to receive an ICR. This improves the timeliness for detecting diversion.

SLAFKA also demonstrates the benefits of a shared ledger in managing safeguards information. Figure 3 illustrates the differences between current safeguards reporting and SLAFKA safeguards reporting. In the latter, instead of holders of nuclear material reporting directly to a regulator which in turn submits information to the international regulator, holders digitally transact between one another and the regulator(s) observe and verify the transactions. In a DLT system, state (and regional/international regulator) records are the same, eliminating the time spent by inspectors to reconcile state and operator records. The ledger becomes authoritative with inspectorates accessing the same data.

Given SLAFKA is fictional and used for demonstration purposes publicly, it was not designed to provide a secure environment and therefore did not test security features of DLT. It assumed that participants had already agreed upon consensus in data validations. As mentioned above, SLAFKA did demonstrate how permissioned DLT platforms can design access controls to align with confidentiality rules.

4 Next Steps

Since its launch in March 2020, SLAFKA has been demonstrated in over 30 closed or open webinars, raising awareness and a wealth of feedback on the potential for DLT to create greater efficiencies in managing safeguards data. Next step for SLAFKA is to present in-person at Euratom once travel and health restrictions allow. In the meantime, the Stimson Center is discussing with a wide range of stakeholders the potential to test the tech in different legislative context and at the facility level, such as accounting for civilian nuclear material in a weapons state. Future research is also needed to explore:

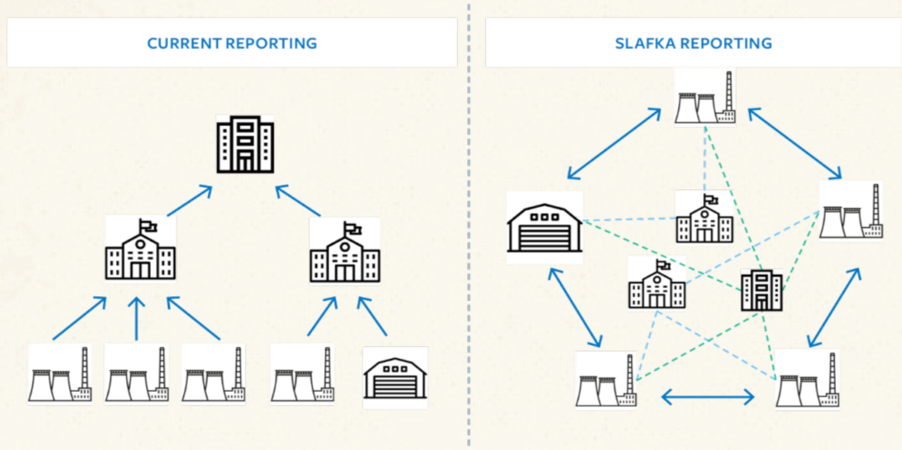


Figure 3: Present-day safeguards reporting and SLAFKA safeguards reporting[10]

- Other safeguards transactions such as those related to the Additional Protocol and bilateral nuclear cooperation agreements (NCAs). The latter would include more participants in a DLT platform and would have to address a variety of export control regulations specific to NCAs.

- Security and specific functionality of DLT architecture and how it could be integrated as a layer in current safeguards management databases, particularly in a regional (Euratom) or international (IAEA) context

- Data related to nuclear security and safety to increase understanding about the applicability of a DLT to incorporate the "3S" principles of safeguards, security, and safety

- Costs for deployment (and whether benefits outweigh costs).

Nuclear technology is a disruptive technology itself and as a such the rules, regulations, regional and international treaties that have been built up over decades are dedicated to keeping the technology from being disrupted. The community is rightly skeptical about breakthrough technologies. SLAFKA is a first of many steps in researching and testing the functionality, usability, and acceptability of DLT for nuclear safeguards information management.

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KEY CHARACTERISTICS FOR PROLIFERATION-RESISTANT GENERATION IV REACTORS

by T.A. BOYTSOVA
(SC «VNIINM», High Technology Science Research Institute of Inorganic Materials, Russia)
(Participant of the 18th ESARDA Course, selected student essay)

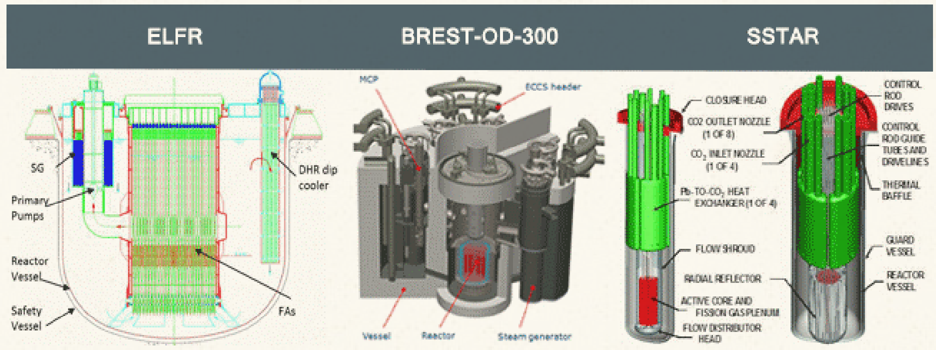

Fig.1 Three types of fast neutron reactors with lead or lead-bismuth cooling agent

«Generation IV nuclear energy systems will increase the assurance that they are very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism» [1]. That is one of the eight goals of GEN IV reactors international forum (GIF) about proliferation resistance and physical protections.

Based on these goals more then 100 experts studied about 130 proposals with the description of reactor concepts and only six kinds of reactors have been chosen. These reactor are: Gas-cooled Fast Reactor (GFR), Lead-cooled Fast Reactor (LFR), Molten Salt Reactor (MSR), Supercritical Water-cooled Reactor (SCWR), Sodium-cooled Fast Reactor (SFR) and Very High Temperature Reactor (VHTR). To begin with we will have a closer look at these reactors.

GFR is a fast reactor with high-temperature helium cooling and closed fuel cycle. It is possible to use this type of reactor to burn long-lived actinides. The fuel of GRF can also be multi-recycled. High density fuel such as nitride or carbide, which allows to burn and breed plutonium and burn minor actinides (MA) is used in this type of reactor [2,3].

LFRs – reactors with fast neutron spectrum, are working at a range of high temperatures and using melted lead or lead-bismuth as a cooling agent. At the same time LFR can be plutonium breeder and burn MA. Such reactors are European ELFR lead-cooled system, Russia's BREST-OD-300 and the SSTAR system concept designed in the US [4,5,6].

There are also some other reactors of the same type in China, Russia, US, Sweden, South Korea and Japan, except presented on the picture 1 [7,8].

SFR uses liquid sodium as a coolant and plutonium and uranium mixed oxides or metal alloys as a fuel. Reactors such as Phenix reactor in France, Monju in France and BN reactors in Russia proved the possibility to implement such type of fast [9,10].

MSR is different from other types of reactors because it doesn't use solid fuel. The reactor core of MSR is filled with melted chloride or fluoride salts: mixture of carrier salt and actinide chlorides or fluorides. MSR can be used as commercial reactor to produce electricity or as a burner, for MA disposal. MSR can work in thermal as well as in fast neutron spectrum. There are different types of molten salt reactors that can use plutonium or thorium salts as a fuel [11-16].

SCWR – reactors with water cooling that works in a range of high temperatures and high pressure (374°C, 22.1 MPa). This type of reactor uses thorium fuel and according to its design can work in thermal or fast neutron spectrum [17-19].

VHTR uses helium as a cooling agent. It also works in thermal range of neutrons. TRISO elements are used as a fuel. VHTR can also support fuel cycles based on U-Pu, Pu, MOX, U-Th fuels. [20]

Technical characteristics of the main GEN IV reactors are presented in Table 1.

Reactor	Neutron spectrum	Cooling agent	Working temp. °C	Fuel cycle	Power (MWe)
VHTR	Thermal	Helium	900-1000	Open	250-300
SFR	Fast	Sodium	500-550	Closed	50-150 300-1500 600-1500
SCWR	Thermal / Fast	Water	510-625	Open / Closed	300-700 1000-1500
GFR	Fast	Helium	850	Closed	1 200
LFR	Fast	Lead/ Lead-bismuth	480-570	Closed	20-180 300-1200 600-1000
MSR	Thermal / Fast	fluoride/chloride salts	700-800	Closed	1000

Table 1. Main characteristics of GEN IV reactors [1]

The aim of this work is to determine and discuss main possible proliferation resistant characteristics of GEN IV reactors.

At the beginning it is important to determine terminology and choose the most optimal way to carry out analyses of GEN IV reactors characteristics relevant to proliferation resistance. According to IAEA-TECDOC-1434 "proliferation resistance" is defined as a characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by States intent on acquiring nuclear weapons or other nuclear explosive devices. The degree of proliferation resistance results in a combination of, inter alia, technical design features, operational modalities, institutional arrangements and safeguards measures. All of that can be classified as intrinsic features or extrinsic measures. The intrinsic features are usually determined by the design of nuclear system. The extrinsic measures are the result of State decisions and obligations about the use of nuclear systems. All Gen IV systems are still developing so it makes impossible to apply extrinsic measures to them. For that reason, all the attention in this paper will be payed to the intrinsic measures of proliferation resistance for nuclear systems. To choose the list of intrinsic measures that can be used we will look though several evaluation methods of nuclear systems proliferation resistance.

The first in the list is method called ***TOPS (Technology opportunities for increasing the proliferation resistance of global civilian nuclear power systems)***, according to which proliferation resistant measures (barriers) are divided into three groups [21,22]. The first group describes fissile material and includes such characteristics as isotopic and chemical composition, ionizing radiation, concentration, and detection of nuclear material (NM). The second group is about nuclear system and include: attraction of material, probability of diversion, available amount of NM, experience, knowledge and diversion time. The third one describes extrinsic factors such as safeguards, physical protection and location of the nuclear system.

The next method is ***MAUA (Multi-attribute utility analysis)***. It was developed to conduct comprising analyses of proliferation resistance for different fuel cycles and nuclear systems [23]. This method presents several equations and parameters to perform quantified evaluation of such characteristics as type and physical form of nuclear materials, radiated heat, weight quantity of plutonium isotopes, concentration of NM related to significant quantity (SQ), dose of radiation, ability to separate NM (separation of weapon grade NM), precent amount of stages in the process where safeguards are applied, probability of theft, physical barriers and its contribution, duration of the process.

PRPP (Proliferation Resistance and Physical Protection) method developed and used by GIF. The main determined parameters are technical complexity, cost of usage and modification of peaceful nuclear energy systems to produce weapon, probability to detect diversion or misuse of NM, human resources and necessary cost to provide safeguards and physical protection of nuclear system under

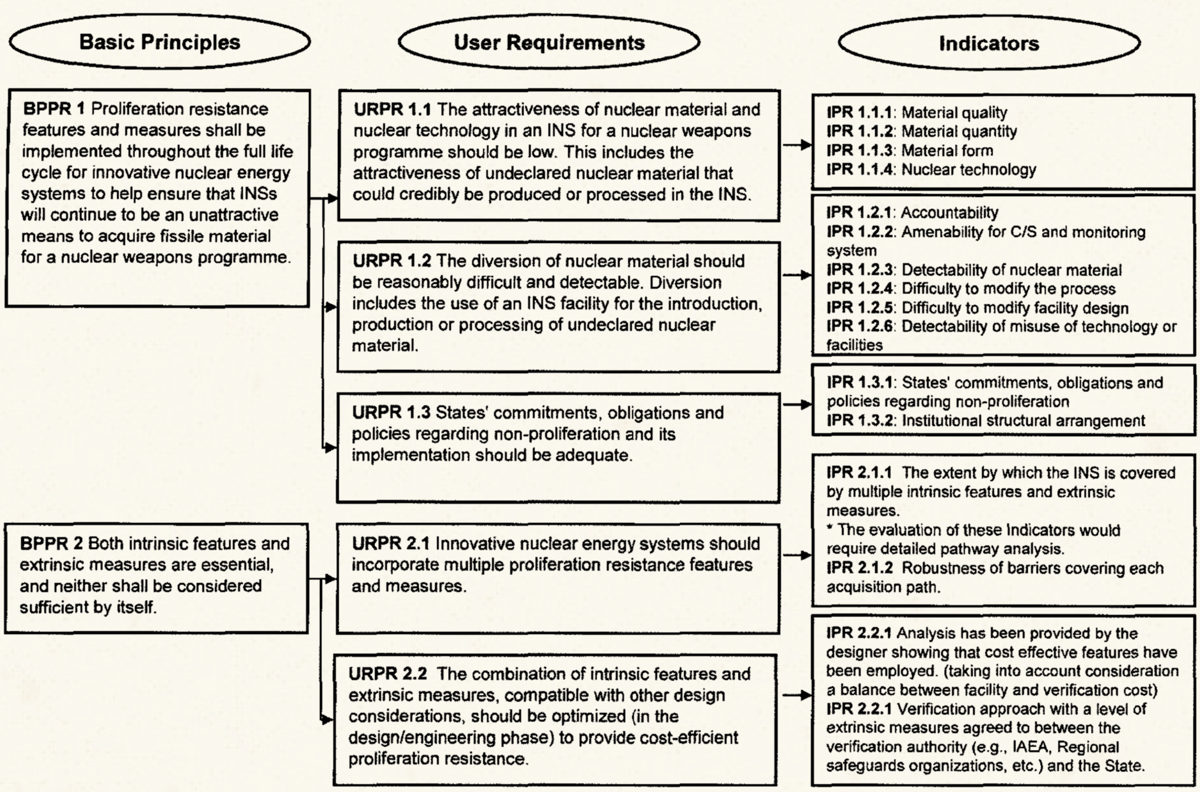

Fig.2 The struxture of INPRO methodology for PR evaluation presented in IAEA-TECDOC-1434 [25]

consideration [21].

FLB (Fuzzy logic-based barrier method for the evaluation of the proliferation resistance of nuclear fuel cycle systems) is based on calculation of extrinsic barrier efficiency functions for which the group of dependent variables or quantity variable parameters are used. These variables and parameters can effect proliferation resistance system under consideration [24]. The list of barriers developed by DOE to characterize proliferation resistance (PR) was similar to one of TOPS and used as a basis for FLB.

The main objects of ***INPRO PR*** method are basic principles that are being used by IAEA to evaluate proliferation resistance of every new nuclear system [21]. These principles and their connection to PR characteristics are presented on picture 2.

It should be noticed that all methods of proliferation resistance evaluation above consider NM that is used in the system, forms of these materials, quality and quantity, elemental and isotopic composition, their attractiveness and if they can be easily used for nuclear weapon production. Therefore, it is possible to say that a key component in proliferation resistance evaluation of the GIV IV nuclear systems that should be determined is nuclear fuel. Its' own characteristics and ways to manage and storage it will be considered in this paper. Types of fuel used in GEN IV reactors are presented in table 2.

System	Type of Fuel (options)
VHTR	• TRISO coated particle fuel • Alternative:U-Pu, Pu, MOX, U-Th fuel
SFR	• mixed oxide • mixed metal alloy
SCWR	• thorium fuel
GFR	• dense fuel such as carbide or nitride (provides plutonium breeding) • option: minor actinide burning
LFR	• dense fuel such as nitride (provides plutonium breeding) • option: minor actinide burning.
MSR	• molten fluoride or chloride salt including Th, U, Pu • option: burners of all transuranic elements

Table 2. Fuel used in GEN IV nuclear systems

The first characteristic of the fuel that should be discussed is its isotopic composition. It should be noticed that most of the fuel types for the fast neutron reactors include or might include plutonium. In this situation SCWR reactor is an exception because it uses thorium fuel. Obviously, Pu will present in fuel as a mixture with U-238, that will lead to Pu-239 accumulation as well as in the classic thermal reactors. In this case it is important if the composition of the fuel loaded into reactor was an equilibrium. If it was, then in this case the amount of plutonium that will burn during the period of fuel presence in the reactor will be equal to the amount of Pu that will accumulate. If the composition of the fuel isn't equilibrium it means that irradiated fuel will contain more plutonium that it was in the fuel before irradiation and all of it will negatively influence the proliferation resistance of the nuclear system. The second issue that should be considered is the opportunity of nuclear reactor to burn MA. This is also about the equilibrium composition of the fuel, but in this case presence of MA in fuel increases its radioactivity, which makes it harder to manage, and as a result has a positive effect on the proliferation resistance of the reactor.

Next characteristic under consideration is a physical form of fuel elements and possible ways ot storage it. For most types of reactors solid fuel is proposed, which means that fuel assembly contains fuel tablets of solid nitride, carbide or oxide fuel. Metal fuel can be also considered as a solid one. All this fuel tablets have claddings which also gave it an extra layer of protection. As for MSR melted chloride or fluoride salts containing TRU would be used as a fuel. All these salts should probably be packed into the containers for transportation or storage.

MSR fuel can be two types that are depend on the purpose of the reactor. If it is a commercial reactor to produce electricity, then Pu will present in the composition of the fuel and the absence of the cladding and being packed in the container will make it easy to handle. All of it will make this reactor less proliferation resistant. If this type of reactor will be used to burn MA, they will present in a fuel and will make it harder to manage because of the increased level of radiation. As a result it will lead to the increase of proliferation resistance of MSR. For all mentioned types of fuels the best way to extract plutonium is to use pyrochemical methods. These methods are also very attractive from the point of view of proliferation resistance because of a close electro-chemical potentials of the actinides which make it impossible to separate heavy metals from each other. The obtained undivided mixture of actinides is also very difficult to manage during the reprocessing due to its high level of ionization radiation. Its handling probably requires technology of distant management and specially equipped facilities.

Since fuel reprocessing was already mentioned above the next parameter to discuss is a fuel cycles that can be proposed for these six types of reactors. According to the data presented in Table 2 only VHTR can have open fuel cycle. For all other GEN IV reactors closed fuel cycle is expected, that means that Pu, U and MA will be separated from fission products (FP) and recycled. Nowadays the most verified technology for SNF reprocessing is hydrometallurgy. This reprocessing technology was the main one to obtain weapon grade Pu from irradiated fuel. It allows to achieve purification coefficients of target components from FP about 105-107. Hydrometallurgy technology have been developed to separate weapon grade Pu with a required purity for military use, so its proliferation resistance is not high. To increase it the methods of physical protection are usually used.

The other technology, that is right now is under developing in many countries is a pyrochemical technology. As it was said above its main advantage from the point of view of proliferation resistance is a possibility to recover actinides together without its separation from each other. At present time this technology is not fully developed and didn't recover actinides with necessary purification coefficients for its further reusing. Due to this reasons different combined pyro-hydro reprocessing technologies are developing [26].

The radioactive barrier has been already mentioned above during the discussion of isotopic composition and physical form of the fuel. The main issue here is a presence of MA in the nuclear fuel, which increases the radioactive background and makes harder handling of such type of fuel. It should be taken into account that period of work of different electronics is shorter in a place with high radiation background. Due to that organizing of distant or robotized management of the SNF becomes very challenging. On the other hand, considering such fuel characteristic as detectability the determination can be complicated by an extra gamma emitting fission products presenting in the fuel. The high radioactive background from the MA can also prevent correct accounting of NM in the places of fuel storage before loading into the reactor and after its irradiation.

In the presented work GEN IV reactors and some methods for proliferation resistance of nuclear systems were considered. It was noticed that the main part of each method is evaluation of NM presented in the nuclear system under consideration. Different types of fuel for GEN IV reactors were considered. Such characteristics of nuclear fuel as isotopic composition, physical form, radioactivity, detectability, management, and reprocessing were analyzed. These characteristics are common for many methods for proliferation resistance evaluation. During the analysis of Gen IV reactors, it was shown that the same characteristics of the nuclear fuel can at the same time decrease and increase proliferation resistance of nuclear systems. It depends on comprehensiveness of evaluation method which was used. Thus, until it would not be a universal system of quantitative evaluation method of proliferation resistance, all attempts in this field to calculate PR of nuclear systems will be judgmental. For this reason, it is important to find a way to develop method that can be mostly based on calculations.

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