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Connector

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EDITORIAL

by Julie Oddou (ESARDA President)

Dear Reader,

The agenda of Year 2022 is very busy in terms of Safeguards events and ESARDA will contribute to all the discussions in these events.

First I would like to recall that the 2022 ESARDA Annual Meeting is planned to be held at the Luxembourg Congress Conference Centre, Luxembourg, from 2-5 May 2022. This annual meeting is a closed meeting reserved to ESARDA Parties, all our Associated and Individual Members and of course ad hoc contributors on invitation. Monday afternoon will be dedicated to the Steering Committee and Executive Board Meetings. Tuesday 3 May is the Plenary Day with some keynote Speakers in the morning and topical discussions in the afternoon. The Working Groups' sessions will take place on Wednesday and Thursday, before closing the Meeting on Thursday 5 May in the afternoon.

Also the ESARDA Course 2022 on Nuclear Safeguards and Non Proliferation (20th edition) will be organized on-line from 6 to 20 May and will feature a full five-days program with

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lectures, group exercises and virtual visits of some JRC Ispra research laboratories. The course is open to anyone but is especially relevant for master degree students and young professionals in nuclear engineering or in international relations and law.

During the 12th Annual Meeting of the Asian Pacific Safeguards Network, which was held virtually from 24th - 25th February 2022, I presented some updates about our recent activities, including the ESARDA Bulletin (now indexed in Scopus), our 2 new Working Groups and the new Master Course on Nuclear Safeguards opened by ENEN and organised by Politecnico di Milano (POLIMI) with the help of the JRC.

Past ESARDA Annual Meeting at the Luxembourg Conference Center

The next conferences (ESARDA Annual Meeting in May in Luxembourg, INMM Annual Meeting on-line in July and the IAEA Safeguards Symposium in Vienna in November) will give us many opportunities to continue our joint work all together in Europe and with our partners in the world to reinforce Safeguards.

The ESARDA Steering Committee was held virtually on November 29th 2021. During this meeting, one new candidate party, Westinghouse Electric, Belgium, presented its activities as was approved as new ESARDA party. The newly signed non-traditional partnership with IAEA was presented and discussed; this agreement is a good opportunity to formalize our framework with IAEA and increase our relevance and effectiveness in supporting IAEA. Under this umbrella, we discussed ESARDA's support to the forthcoming 2022 IAEA Safeguards Symposium. ESARDA will, as always, participate in chairing and/or contributing in sessions and panels ; in addition 3 Steering Committee's members volunteered to participate in the Symposium Technical Program Committee. The revision of the ESARDA rules and procedures and ESARDA agreement was discussed in lenght. The proposed drafts were submitted upfron to the meeting and the proposed main revisions were presented during the meeting. Based on the discussions' outcome, new revision will be drafted and proposed for adoption in the Spring 2022.

The Executive Board was held virtually on December 1st 2021.The Executive Board reviewed and approved the content of the ABAC and ESARDA Memorandum of Understanding (voted during the last Steering Committee). The agreement will be signed by both parties in the near future. The status of the Editorial Committee (see below) and the revision of the ESARDA rules and procedures and ESARDA agreement was on the agenda as well as a reflection on potential organisations to outreach to and the organisation of the next annual meeting. The WG chairs reported on their 2021 activities and provided feedbacks and set of recommendations from the 2021 Annual Symposium

The Governance of ESARDA is in the process of reviewing the rules and procedures of the association and in parallel the content of the ESARDA Agreement itself. One major evolution is the decision to give a new status to the Editorial Committee, as a permanent body of ESARDA and to clearly define its role based on what it is already doing. The Editorial Committee is therefore responsible for the validation and dissemination of publications of the association (the ESARDA Bulletin, the Connector and the ESARDA Symposia and Workshop Proceedings) and remains in charge of organising the review and the selection of the papers to be published. Working in close cooperation with the Executive Board, it will be responsible for developing and implementing the ESARDA communication strategy (both internal and external) through the website, CIRCABC document repository or other short communications (including in social media).

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

ESARDA Bulletin Impact Factor

The ESARDA Bulletin is into its second year as being indexed (CiteScore tracker) in Scopus, and since December 2021 the publication has also been assigned an impact factor. Albeit very low, the impact factor marks an important achievement for the Bulletin's prestige, as the impact factor measures the average number of citations to articles published in peer-reviewed academic journals. As a metric for a journal's measure, it is often adopted as a factor for the relative importance of a journal within its field.

The ESARDA Bulletin is the only peer-reviewed scientific journal fully dedicated to the multidisciplinary area of nuclear safeguards, making it an invaluable tool to foster scientifically sound nuclear safeguards scientific knowledge in support to better nuclear non-proliferation regulations, policies, implementation. Its multidisciplinary nature provides a dissemination mean for safeguards research that would not be fully on-topic on previously existing peer-reviewed scientific journals, impairing the possibility to disseminate scientifically sound knowledge critical for the improvement of the non-proliferation regime's effectiveness and efficiency.

To increase the impact factor, the ESARDA Bulletin must keep up the consistency of the quality of articles being published. The Editorial Board invites all the ESARDA Community to contribute high- quality articles that have an impact on the safeguards discipline.

IAEA document on Resource Mobilization Priorities

In order to mobilize support from stakeholders the IAEA has published the Resource Mobilization Priorities, this document identifies a prioritized set of capabilities the Safeguards Department needs and for which the agency is seeking external support, ranging from R&D to expertise and financial support. Sustaining and developing these capabilities is essential to overcome challenges and seize opportunities.

The document presents the Resource Mobilization Priorities (RMP) 1 of the Department of Safeguards for enhancing its capabilities. These priorities are identified within the departmental strategic planning framework.
To broaden IAEA's support base, the agency is working to expand and diversify partnerships and invite new partners to consider these priorities, find areas of mutual interest, and get involved.

Having recently signed an agreement with IAEA, ESARDA is one of the key external partners that can provide its expertise in the field of safeguards and provide assistance in facing the hurdles presented in these unstable times.

The article can be found here:
https://www.iaea.org/sites/default/files/22/02/rmp-2022.pdf

50 years of the IAEA Safeguards in Finland according to the Comprehensive Safeguards Agreement (CSA)

The 9th February 2022, marks 50 years since Finland was the first country to conclude a Comprehensive Safeguards Agreement (CSA) with the International Atomic Energy Agency (IAEA). The achievement paved the way for Finland to lead the way in the safe use of nuclear energy. CSA is based on the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), which constitutes the main objective and preconditions for the peaceful use of nuclear energy.

STUK published a report "Nuclear Non-Proliferation and Finland - 50 Years of National Implementation of the Non-Proliferation Treaty" in the anniversary year of the Treaty in 2020.

The report can be found here:
https://lnkd.in/eihi38Uy

IAEA Open Access Book 'Nuclear Law - The Global Debate'

This book is part of the IAEA's First International Conference on Nuclear Law that takes place in April 2022. Experts from around the globe have contributed with a collection of essays that bring together insights on the challenges and issues of nuclear law.

A number of essays focus on the history of nuclear law and its projection into the future, others are dedicates to specific issues in the main fileds that make up nuclear law, such as safety, security, safeguards and nuclear liability.

This book is open access, and my be freely accessed at the following link: https://link.springer.com/book/10.1007/978-94-6265-495-2

Academic publication on Trade control and dual-use research available from University of Liège

Former ESARDA Export Control Working Group Chair, Professor Quesntin Michel, has made available on the University of Liège website a new publication on Academic proliferation: *'Trade control and dual use research: a difficult compromise'*.

In this publication, the delicate subject on the necessity to restrain from the dissemination of knowledge and discoveries among scientists to avoid their potential misuses, is discussed.

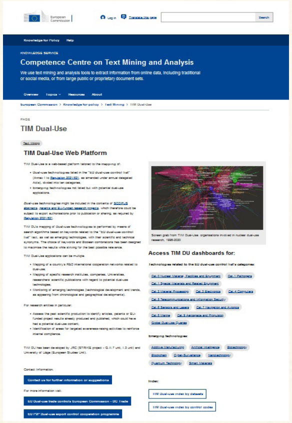
The article can be found here: https://www.esu.ulg.ac.be/wp-content/uploads/2022/02/T%D0%A1_difficult-compromise.pdf

TIM Dual Use Web-platform Update

In the fourth issue of the Connector the TIM Dual-Use web platform was featured in an article written by Dr. Filippo Sevini, former ESARDA secretary and team leader for Strategic Trade Control at the JRC. The article presented how the JRC Text Mining experts have developed TIM Analytics 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.

With the cooperation of JRC Nuclear Security experts and Liège University, TIM has been customised for dual-use technologies related queries associated with each of the 10 categories of items listed under EU Dual-Use Control List (Annex I to Regulation (EU) 2021/821), as well as emerging technologies with potential dual-use applications.

In order to facilitate the user, the JRC, in collaboration with Liège University, has provided two indexes to guide users in navigating the TIM Dual-Use platform by control codes and by datasets. The Indexes operate as a correlation table helping the users to easily identify in which space and dataset of the platform is possible to find data on a specific dual-use item or emerging technology starting from either a keyword (Index by datasets) or the control code of the Annex I of the EU Dual-Use Regulation (Index by control codes). The Index is composed by the headings indicating the TIM DU's space (dual-use category or



TIM Dual-Use webpage

emerging technology),and three columns displaying the "EU Dual-Use Control List" control codes and the corresponding TIM DU's datasets and queries' keywords.

The TIM Dual-Use web-based platform can be accessed at the following link: https://knowledge4policy.ec.europa.eu/text-mining/tim-dual-use_en

EVENTS

2022
April
25-28

25th - 28th April 2022

Conference on Fast Reactors and Related Fuel Cycles (FR22)

Beijing, China

The International Atomic Energy Agency (IAEA) once again brings together the fast reactor and related fuel cycle community by organizing the International Conference on Fast Reactors and Related Fuel Cycles: Sustainable Clean Energy for the Future (FR22). [Read more]

2022
May
2-6

2nd - 6th May 2022

ESARDA 44th Annual Meeting

Luxembourg Congress Conference Centre, Luxembourg

The 2022 ESARDA Annual Meeting is planned to be held at the Luxembourg Congress Conference Centre, Luxembourg, from 2-6 May 2022. This annual meeting is a closed meeting reserved to ESARDA Steering Committee, Executive Board and Working Groups' members, i.e. Parties, Associated and Individual members and ad hoc contributors, as agreed by WG Chairs. [Read more]

2022
May
16-20

16th - 20th May 2022

20th ESARDA Course

Online Course

The European Commission, Joint Research Centre announces the 20th ESARDA Course on Nuclear Safeguards and Non-Proliferation being co-organised by the European Commission's Joint Research Centre and the Training and Knowledge Management Working Group (TKM) of ESARDA. [Read more]

2022
July
24-28

24th - 28th July 2022

63rd INMM Annual Meeting

Virtual Meeting

The INMM Annual Meeting is the centerpiece of INMM's program year. Join your colleagues from around the globe for this rich educational and networking event. This event will take place as a virtual event in July 2022. [Read more]

2022
Oct. - Nov.
31-4

31st October - 4th November 2022

Symposium on International Safeguards: Reflecting on the Past and Anticipating the Future

Vienna, Austria

The Secretariat of the International Atomic Energy Agency (IAEA) presents the Symposium on International Safeguards: Reflecting on the Past and Anticipating the Future to be held at the IAEA's Headquarters in Vienna, Austria, from 31 October to 4 November 2022. [Read more]

IAEA

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.

STANDARDS AND TECHNIQUES FOR DESTRUCTIVE ANALYSIS WORKING GROUP (DA)

by Stefan Neumeier (DA WG Chair), Evelyn Zuleger (DA WG Vice-Chair), Philip Kegler (DA WG Vice-Vice-Chair) & Brian Ticknor (DA WG Chair, INMM)

The ESARDA Working Group on Standards and Techniques for Destructive Analysis (DA) is providing the Safeguards Community with an expert advice on reference standards, procedures, and analytical techniques for the analysis on a wide range of safeguards samples.

Since the last joint INMM/ESARDA DA WG meeting held within the INMM/ESARDA Joint Annual Meeting in Aug./Sep. 2021 DA WG members participated in and contributed to several meetings together with the IAEA, e.g. "Technical Meeting on Particle Analysis of Environmental Samples for Safeguards Purposes", held online in December 2021. Based on these meetings Forschungszentrum Jülich (FZJ), Joint Research Centre, Geel (JRC-Geel) and the IAEA's Office of Safeguards Analytical Service, Seibersdorf/Vienna (IAEA-SGAS) agreed upon the production of new U-oxide based microparticle reference materials which are planned to be finalised within 2022.

In addition, significant progress was achieved with regard to certified reference materials (CRMs) at the NBL Program Office (Pu isotopic CRM 137 recertification underway along with new U and Pu metal and Np CRMs), at JRC-Geel (released: 5% 235U "Monodisperse" Microparticles (IRMM-2331P); 20 - 90% 235U nitrate solutions (IRMM-3000 series); 6% enriched 235U (IRMM-2030); LSD spikes IRMM-1027u and -v (235U, 238U and 239Pu); planned for 2022-2024: Recertification (IRMM -183-187 series); LSD spikes (IRMM-1027w; IRMM-1038); 233U (IRMM-040b) & 233U/242Pu (IRMM-046d) spikes) and at CEA-CETAMA (Pu metal CRM MP4 certification process launched at the end of 2021).

A lot of DA members from INMM and ESARDA participated in the IAEA effort to update the International Target Values (ITV) which is now close to completion. Four of the twelve subgroups dealt with nine different methods used for destructive analysis. Finally, five tables with more than 100 ITVs were revised. Only minor steps remain to finalize the ITVs.

In response to the ESARDA World Café Topic 2, the ESARDA WGDA was also represented in the Technical Meeting on Artificial Intelligence for Nuclear Technology and Applications held online from 25 to 29 October 2021. This meeting included a working group on Artificial Intelligence for Safeguards. It was acknowledged that dedicated workshops hosted by ESARDA could help to bridge the gap between AI/ML experts, industry and regulators avoiding silo development and increasing acceptance.

The Specialising Master Program in Nuclear Safeguards organised by the European Nuclear Education Network (ENEN) started in October 2021. The DA related Module 7 is scheduled in March 2022 and is prepared in collaboration with the University of Milan and the JRC Geel, JRC Karlsruhe and the IAEA. The online videos and webinars will cover the following topics: (i) Sampling and sample preparation for destructive analysis (DA); (ii) Thermal ionisation mass spectrometry (TIMS) and isotope dilution mass spectrometry (IDMS) for analysis of safeguards samples; (iii) Hybrid K-edge and COMPUCEA (Combined Procedure for Uranium Concentration and Enrichment Assay) for analysis of safeguards samples and (iv) Sampling and analysis of environmental samples. A member of the ESARDA WGDA was invited to give an online seminar lecture to pupils from secondary of the European school in Mol, Belgium, about EURATOM safeguards and Atoms for peace, including some of the ESARDA WGDA activities. The master program and the reach-out to pupils in school are directly supporting ESARDA's World Café Topic 6 and Topic 9.

The INMM and ESARDA DA WG members agreed to continue and to strengthen the relationship between both associations in several joint meetings: ESARDA DA WG at the ESARDA 44th Annual Meeting in May 02 – 06, 2021 in Luxembourg hopefully in-person; 63rd INMM Annual, Meeting, July 24 - 28, 2022, virtual and INMM/ESARDA Joint Annual Meeting 2023, Vienna.

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 technologies and methodologies – and novel uses of existing technologies and methodologies - to the verification of nuclear safeguards, arms control, and other non-proliferation agreements.

Since our last Communicator update, VTM has held a virtual working group meeting, and finalized a special issue of the ESARDA Bulletin on data analytics for nuclear safeguards and non-proliferation. Upcoming activities include a joint technical exchange with the Institute of Nuclear Materials Management on synthetic and proxy data on March 30-31, and a planned working group meeting during the upcoming ESARDA Annual Meeting in May in Luxembourg. Finally, we share a call for volunteers to support VTM's leadership. Details on all these topics are below.

November 2021 Working Group Meeting

On November 16 and 17, 2021, VTM held a virtual working group meeting. The working group meeting included one day focuses on the third of our three-part "What is?" series related to emerging digital technologies, focused on digital ledger technologies (DLT). Nicholas Pattengale from Sandia National Laboratories (SNL) provided a technical overview of DLT and its current capabilities, DLT use cases in the commercial sector, potential barriers to adoption of DLT and future research opportunities. He also described his recent research incorporating a prototype DLT for safeguards, and the spectrum of safeguards adoption strategies for the technology. Following the overview presentation, several participants shared their own research experience related to DLT and discussed the potential value of DLT, as well as various models of DLT implementation that might benefit safeguards. Working group members who provided remarks on their own research and development related to DLT included Roberto Spigolon from the Joint Research Centre (JRC), Marco Sachy from JRC, Robert Hughes from the UK Atomic Weapons Establishment (AWE), Dermot O'Brien from JRC, and Cindy Vestergaard from the Stimson Center.

The second day of our meeting was a traditional working group session in which members shared research updates on various topics relevant to VTM. These presentations included:

- Carlos Sanches Belenguer of JRC provided a briefing on the RISE project for indoor localization support for inspectors.
- Anton Jakobsson of JRC described technical capabilities for extracting relevant information or events from surveillance cameras from industry, and how they apply to safeguards surveillance cameras.
- Zoe Gastelum of SNL described differences observed in human performance testing between expert and novice users that were engaging with machine learning support on a safeguards-relevant image recognition task.

ESARDA Bulletin Special Issue

In December, the ESARDA Bulletin published a special issue on data analytics for nuclear safeguards and non-proliferation, which was proposed by the Verification Technologies and Methodologies working group. One aim of the special issue was to respond to the 2019 World Café's emphasis on improved communication with our stakeholders related to current state-of-the-art capabilities, research, and the implications of data analytics to support nuclear safeguards and non-proliferation. The special issue featured four peer-reviewed manuscripts on exciting data analytics topics including:

- Using machine learning to predict isotopics, burn up, and cooling time of spent nuclear fuel;
- Developing multi-model machine learning approaches to detect nuclear material diversion in reprocessing;
- Comparing methods of pre-training and fine-tuning language models to classify scientific publications according to stages of the nuclear fuel cycle; and
- Developing a question-and-answer system that was calibrated to nuclear non-proliferation topics that included an audit capability.

The special issue is available on the Bulletin's website, here: https://esarda.jrc.ec.europa.eu/publications-0/esarda-bulletin_en

Upcoming Events

On March 30 and 31, 2022, the VTM working group will jointly host a technical exchange with the Institute of Nuclear Materials Management (INMM) Open Source and Geospatial Information working group on the use of synthetic and proxy data for nuclear safeguards and non-proliferation research and development activities. The discussion is intended to cover questions such as:

- What synthetic or proxy data are members currently using in their research? How are they using it? What is the role – if any – of real-world data?
- How might we responsibly curate and validate synthetic or proxy datasets?
- How might we prove transferability without access to real safeguards data?
- What are the infrastructure, privacy, proliferation, or other concerns related to the use of synthetic and proxy data? How are these different with synthetic and proxy data compared to real data?

The technical exchange will be hosted virtually, from 8:00 – 9:30 am Pacific Time, 5:00 – 6:30 pm Central European Time each day. We welcome prepared remarks from those who have worked with synthetic or proxy data for nuclear safeguards and nonproliferation, and anyone may participate in the discussion.

VTM is planning a working group session as part of the ESARDA 44th Annual Meeting to be held in Luxembourg May 2 through 6, 2022. We are currently planning the technical agenda and working group members are encouraged to share research updates.

Finally, VTM wishes to thank Cristina Versino for her year of service as the VTM vice-chair! Cristina was the driver behind the successful three-part "What is…?" series on emerging information technologies, and a strong technical and organizational influence in VTM during her service. VTM is currently seeking volunteers or nominations for vice-chairs. Contact Zoe Gastelum if you are interested in volunteering (zgastel@sandia.gov).

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.

In 2021, the WG organised two meetings: in August in connection with the INMM-ESARDA joint annual meeting and in November. Both meetings were organised virtually.

The first meeting was practically organised as an open meeting, thus enabling high level of attendance of members from INMM and ESARDA, and the associated limitations due to the security of the information discussed during the meeting, the meeting was organised in a short format without e.g. traditional roundtable. Hence, this meeting was the opportunity for the group to discuss the status updates of the projects it is involved in.

The second meeting was organised as a closed meeting, including the roundtable discussions. At the meeting, we agreed on measures to be implemented in 2022-2023 during the term of Marko Hämäläinen, who took over as chairman oft he WG in January 2022. Marianne Calvez was elected as the new vice chairman of the working group.

in 2022, ESARDA's IS WG will also aim to appear in international fora, the most important of which is the IAEA safeguards symposium, where e.g. a paper and presentation will be prepared by the members of the working group about the 25th anniversary of the Additional Protocol to the Comprehensive Safeguards Agreement.

The IS working group usually holds a two-day meeting twice a year. The current plan is to hold a working group meeting during the ESARDA annual meeting in May and, if possible, in hybrid mode. The meeting is currently planned to consist of two parts, a half-day, practically open meeting on topical issues and a one-day closed meeting where confidential matters can be discussed within the group, including a round table. A second meeting of the working group is scheduled to take place sometime during the autumn, and the presence of members of the working group will be requested for this meeting, if the Covid situation allows.

featured articles

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

DEVELOPMENT OF A SPECIALIZING MASTER PROGRAM ON NUCLEAR SAFEGUARDS AND NON-PROLIFERATION

by M. Ricotti, S. Sancassani
(Politecnico di Milano)
G. Pavel
(European Nuclear Education Network)
Willem Janssens
(European Commission - Joint Research Centre)

Abstract

Nuclear Safeguards and Non-Proliferation is largely, if not totally, absent in many nuclear academic curricula. Some short courses are being offered, typically for 1 or 2 weeks on an annual basis, teaching about this topic, e.g. the technical-based courses organized by ESARDA and BNL and the international nuclear law school by the OECD/NEA in collaboration with the University of Montpellier.

The European Nuclear Education Network (ENEN) received the request from the European Commission (DG-INTPA), in the framework of the actions devoted to development cooperation, to implement a full-fledged master course on nuclear safeguards. The specializing master will be organized by Politecnico di Milano (POLIMI) with substantial support of the European Commission Joint Research Centre.

The course is addressed in a first instance to students outside Europe and will be organized mainly in a virtual manner. The Specializing Master is conceived with an integrated approach, based on active learning methodologies, harnessing the participants' professional and personal experience. Recorded video-lectures and live webinars, provided by key experts working in the field, will be combined with student exercises and coordinated activities, requiring deepening and applying the knowledge and skills acquired. For the evaluation of each module, the learning management system will allow lecturers to interact with students in such a manner that the knowledge accumulated during the lessons will reflect the level of knowledge accumulated by a student. Also, both basic and introductory laboratory (2 weeks in person) and specialized laboratory working sessions (3 to 4 weeks) are foreseen. The latter will also form the basis of the thesis work for the students. The final thesis work will enable the chance of collaborating with industry, NGO's, nuclear authorities, R&D bodies, academia.

The curriculum has been developed under the guidance of a Scientific Committee of high-level experts. The students have been and will be recruited, for the following editions, through an active outreach to different geographical areas across the globe. It is also intended to make use of the university network under the International Nuclear Security Educational Network, which in fact is suitably complemented by this new Specializing Master Program.

An introductory module is foreseen to bring students with a variety of backgrounds up to speed with the basic technical nuclear concepts, some inside in related legal and political aspects and an exposure to some webinars of soft skills, which will also be essential for successful implementation of the group work and laboratory session.

The paper describes the current status, i.e., preparation and planning of the master which starts in October 2021.

The Need

The system of international safeguards requires that the National Regulatory Authorities (NRA) and nuclear facility operators, in the Countries where safeguards are implemented, should satisfy specific requirements with respect to the accounting for and control of nuclear material.
European Union is committed to assisting Countries in strengthening the regulatory authorities through the INSC Council Regulation (Euratom N°300/2007)[1] and its subsequent programs.

NRAs must seek the opportunity to train and develop the competences of their employees, 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. This attitude contributes directly to both the national nuclear safety and the implementation of the Countries' safeguards obligations under relevant agreements.
Due to high demands on technical competence especially in the nuclear field, the ongoing availability of new information, the recruitment of new staff, development of new reactor types, new safety mechanisms and new assessment methodologies, one can always find the necessity for general, in depth and/or specialized training for the staff of Nuclear Regulation Authorities (NRAs).

According to safeguards evolution, new approaches and technologies are continuously developed and applied. An urgent need is evident, to widen the education and training approach to a suitable and sustainable program, in the area of nuclear safeguards.

Nuclear Safeguards and Non-Proliferation is largely, if not totally, absent in many nuclear academic curricula.

Some short courses are usually offered on those topics, typically for 1 or 2 weeks on an annual basis. ESARDA and the Brookhaven National Laboratory (BNL) organizes the more technical ones, lasting one or few weeks.

To complete the picture: the International School of Nuclear Law (ISNL)[2] established in 2001 by the OECD Nuclear Energy Agency (NEA) in co-operation with the University of Montpellier[3] and supported by the International Atomic Energy Agency (IAEA), has been designed to provide participants with a comprehensive understanding of the various interrelated legal issues relating to the safe, efficient, and secure use of nuclear energy. The ISNL program has evolved over the last twenty years to address developments in nu-

1 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0237
2 https://www.oecd-nea.org/jcms/pl_23822
3 https://www.umontpellier.fr/en

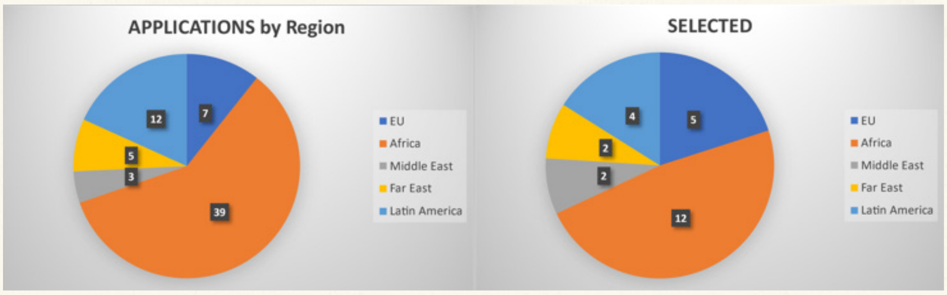


Fig 1: Applications and selected participants by region

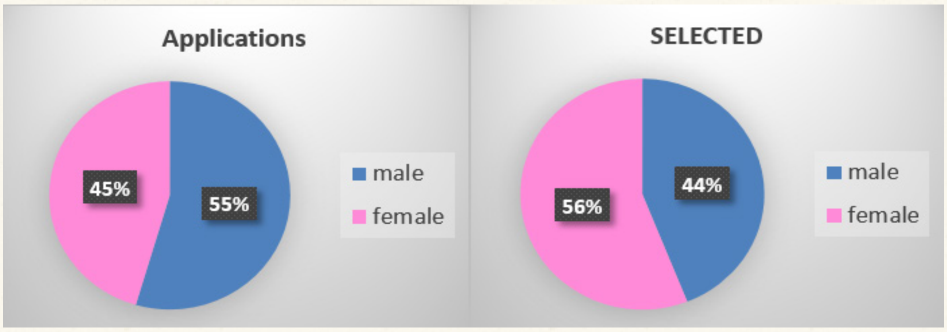


Fig 2: Applications and selected participants – gender balance

clear law and to date, it has addressed more than 1000 graduate students and young professionals worldwide.

To cover the gap in the academic field, the First Level Specializing Master Program on Nuclear Safeguard has been designed, thanks to the collaboration between several European high-level institutions working in the nuclear sector.

The Specializing Master is organized by the Department of Energy of Politecnico di Milano and the European Nuclear Education Network (ENEN), in collaboration with the European Joint Research Center (EU-JRC), with Academic institutions participating in the European Nuclear Education Network, with ESARDA partners and several international organizations (e.g. IAEA).

The Program is meant to provide education and training on a multi-national Master level. This approach will allow for high quality standards and consistent training content. Moreover, it enables the trainees from the participant organizations, to be more versatile and to develop a network of knowledge within EU member states. It will address both technical and legal topics.

The Actors Involved

The First Level Specializing Master Program on Nuclear Safeguards has been designed as a cross divisional training path, involving political science-forensics-nuclear scientific and technological areas, aimed at forming a key group of professionals, ready to be involved in the nuclear safeguards sector at national and international level.

The specializing master involves several high profiles actors, both in terms of organizers and lecturers and in terms of participants.

A Scientific Committee to design the Master has been set up, involving 13 experts from different institutions all around Europe as well as from USA: Politecnico di Milano, European Nuclear Education Network (ENEN), European Commission Joint Research Center (JRC), European Commission DG ENER, International Atomic Energy Agency (IAEA), Belgium Université de Liège (ULg), Forschungszentrum Jülich in Germanu, STUK – Säteilyturvakeskus Finland, SCK-CEN Belgium, Vienna Center for Disarmament and NonProliferation (VCD-NP), Open Nuclear Network – USA.

The Lecturers involved in the specializing master are around 50, mainly coming from the same institutions involved in the Scientific Committee and from the ENEN network. Furthermore, various independent experts with several years of experience in the field will bring their knowledge and expertise in the specializing master.

In terms of participants, the specializing master addresses professionals and promising fresh graduates willing to work in the field. The technical background isn't a must, but a plus, considered during the selection phase: the program has been anyway conceived in such way, that students with weak or without nuclear background will receive enough information to familiarize with the basic principles of the nuclear technology.

The Program addresses all Countries which are part of the Instrument for Nuclear Safety Cooperation (INSC), as defined by European Commission. It includes participants coming from different Countries that are party to the Non-Proliferation Treaty too. Partial scholarships will be provided by Politecnico di Milano, which is managing the Fist Level Specializing Master.

In the first design phase, at least 10 students per academic year were foreseen: the first edition, starting on October 2021, will exceptionally include 25 participants, due to the high number of applicants (66 applications received) and their high profiles. Numbers demonstrate there is high interest in the topic: as shown in Fig.1, applicants come from different geographical areas, particularly from Africa (39).

The 25 selected participants will come mainly from Africa (12), followed by Europe (5), Latin America (4), Middle East (2) and Far East (2).

As for the gender balance (Fig.2), in terms of applications the Females were less than the Males, while in the selection phase the number has been reverted (56% female versus 44% male).

The applicants and selected participants are mainly professionals, employed in Nuclear Regulation Authorities, Technical Support Organizations or Institutions working in the field. Some promising fresh graduates have been selected as well, to support the creation of a new generation of professionals working in the field.

Fig 3: Master organization

Master organization: the blended project-based approach

The Specializing Master Program is conceived as a "blended" master, mixing online and face-to-face activities. This approach will allow students to follow theoretical courses online and in presence practical work, such as hands on experimental sessions and laboratories.

During the design phase of the master (happening during 2019 and in 2020), the blended approach seemed to be the best option: the specializing master was meant to gather attendees from all over the world, with a specific focus on professionals already working in the field. This kind of target doesn't have the possibility to commit an entire year attending a face-to-face Master abroad.

The COVID-19 pandemic emergency confirmed and forced anyway this approach and, at the same time, allowed the development of digital skills for all the actors involved, paving the way for both attendees and lecturers.

The First Level Specializing Master has been designed following a project-based approach: all the contents and the proposed activities have been organized to support the development of skills and competences useful to implement a project, thus supporting the consolidation of effective working approaches.

The Specializing Master will cover 60 ECTs (European Credit Transfers): it has been organized with 12 Online Modules (covering 28 theoretical ECTs, to support the transfer of knowledge and skills) interspersed with 2 Labs experiences ("basic" and "advanced", respectively 5 and 7 ECTs), to consolidate the knowledge and skills acquired during the online modules and to translate them into competences useful when working on the field. A final project work will be developed by the Master participants to apply all the knowledge, skills and competences acquired to finally develop effective methods and approaches, useful in their specific or future working context.

Master organization: the online Modules

The topics covered by the Online modules have been largely discussed and agreed during the several Scientific Committee meetings in 2020. The final configuration is reported in Fig.3.

The first Module will introduce the main legal as well as technical concepts of nuclear safeguards, via webinars and Massive Open Online Courses (MOOCs) uploaded on the POLIMI Open Knowledge Platform (Fig.4)[4]. Furthermore, participants will be required to follow some other MOOCs, to address the soft skills useful when working in similar challenging fields (e.g. Managing Conflicts, Working in Multidisciplinary teams, Negotiation).

After this introductory module covering 3 ECTs, the participants will address the following topics: History of non-proliferation and safeguards (2 ECTs), National and international legal framework (3 ECTs), Fuel cycle and non-proliferation (3 ECTs), Nuclear material and accountancy and mathematical methods for nuclear safeguards (2 ECTs), Methodology for implementation of safeguards (3 ECTs), Destructive analysis (2 ECTs), Non destructive measurements (2 ECTs), Verification and monitoring techniques (including Containment and Surveillance, 2 ECTs), Export control (2ECTs), Nuclear security (2 ECTs), Future challenges in safeguards (2 ECTs).

Each online module will cover two or three weeks, equivalent to the number on ECTs addressed.

The online modules will be organized with a mix of activities: asynchronous and synchronous, individual and collaborative, based

4 https://www.pok.polimi.it/

on frontal teaching and on active approaches.

For each ECTs, Politecnico di Milano is producing videos and multimedia materials in collaboration with METID, the POLIMI Innovative Teaching and Learning task force[5]: participants will start addressing the topic of each module by studying these specific online contents (videos, text and images, quizzes, specific articles – bibliographic material).

Beside the online asynchronous materials, participants will be required to attend two synchronous and active webinars each week: these online meetings are useful to deepen the topic, as well as to discuss and interact with lecturers and all the colleagues.
Finally, for each module, participants will be required to deliver a small project work/report, developed in small working groups.
The final evaluation of each module will take into consideration both the results of online tests organized for each module and the results of the work performed in the teams.
This mix of activities adapts to the different learning styles and needs and, through the active approach, fosters the valorization of the great expertise of the professionals attending the master. At the same time, it stimulates the creation of a community of professionals which will continue after the training experience.

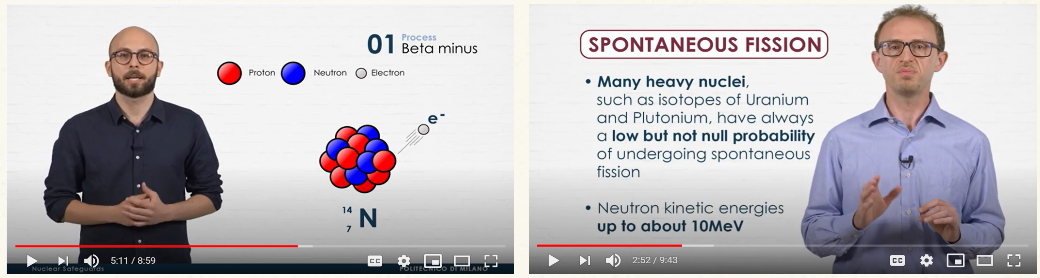


Fig 4: Videos produced for the learning and teaching activities

Master organization: Basic and Advanced Labs

Two Labs and face-to-face experiences, Basic and Advanced, have been planned in the middle and in the final phase of the specializing master experience.

After five Online Modules, participants will spend two weeks in Europe for Basic Labs.
This face-to-face Basic Lab activities will be held in Italy (in Politecnico di Milano as well as in JRC-Ispra experimental labs and in the premises of NGOs based around Milan) and in other renowned labs located in Europe, namely in JRC-Geel and in SCK.CEN-Mol.

As an example, in the Politecnico di Milano laboratories participants will have the possibility to participate in technical sessions held in the laboratories of:

- Nuclear Measurements[6], devoted to the study, the application and the development of methods and techniques for measuring radiation fields of different nature and related properties;
- Radiation Protection[7], carrying out research and services in the field of radiometric measurements;
- Radiochemistry and Radiation Chemistry[8], dealing with chemical aspects within nuclear engineering and technology, with particular attention to reprocessing of spent nuclear fuel and waste manage-

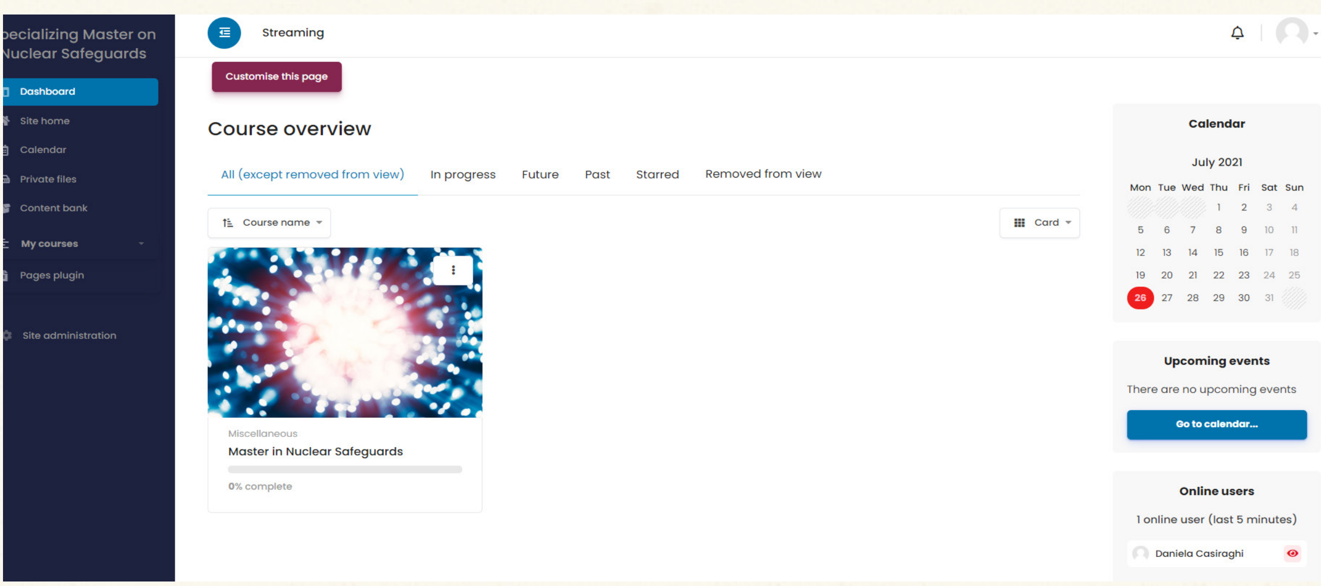


Fig 5: Specializing Master Online Platform - Dashboard

5 https://www.metid.polimi.it/
6 https://www.energia.polimi.it/en/energy-department/laboratories/research-laboratories/nuclear-measures/
7 https://www.energia.polimi.it/en/energy-department/laboratories/research-laboratories/radiation-protection/
8 https://www.energia.polimi.it/en/energy-department/laboratories/research-laboratories/radiochemistry/#c1836

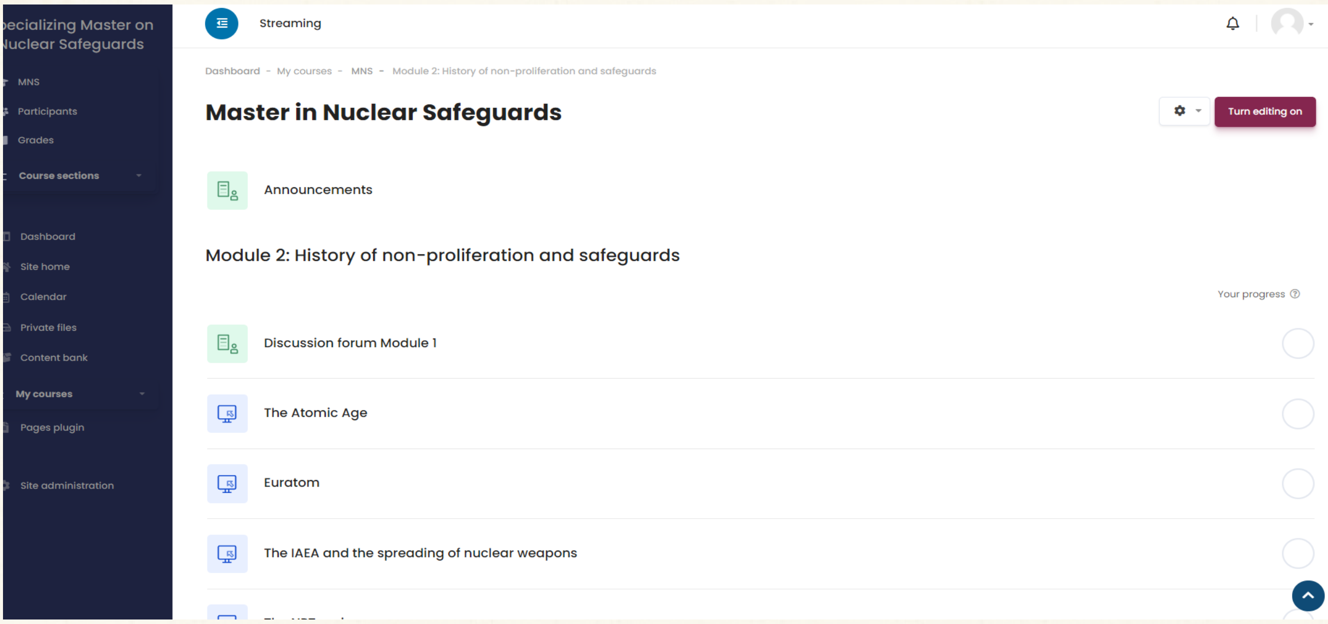


Fig 6: Specializing Master Online Platform – Module structure

ment, decommissioning of industrial and nuclear plants, chemical compatibility within Gen IV nuclear fast reactors.

These technical sessions will be alternated by visits in some NGOs supporting global security, disarmament, and cooperation. A visit to a research reactor (TRIGA type, at LENA lab, University of Pavia) and corresponding facilities will be planned as well.

The Advanced Labs will take place at the end of the training path. They will be organized as tutoring activities of around 3 weeks in technical labs or offices, working in the nuclear safeguards field.

Participants will have the opportunity to deepen a subject they find relevant, also working with experts guiding their action.

Moreover, the Advanced Labs will set the base for the final project work, which will take place after the final module: during this last module, participants will have the possibility to present the first results gathered during the Advanced Labs and discuss with experts the future challenges of nuclear safeguards.

The online platform

The whole master will be managed through an online platform[9] which will act as a "hub" for all the materials, contents, tools, information related to the Master.

The Nuclear Safeguards platform is based on MOODLE, one of the most popular open-source learning management system. MOODLE allows the management of different user's roles, different typology of courses and the integration with various tools.

The external, landing page created on purpose on the platform is freely accessible. It collects all the info related to the specializing master, to spread the news worldwide.
The internal area is accessible via login to all the specializing master managers, lecturers and participants.

The internal area (Fig.5) allows the access to all the courses related to the specializing master editions. Within each course (or edition), the participants will get access to the different modules.
Each module will contain all the materials useful to organize the learning and teaching activities: videos, additional, materials, quizzes, webinars recording held, etc. (Fig.6).

A calendar constantly updated will keep track of all the activities and support the organizational task.

A tutor will be constantly monitoring the participants activities though the platform analytics (gathering data about grades, last activities, last access, etc…): he will remind all the deadlines and keep in touch with the participants in needs.

Conclusions

On a specific and far-sighted request from the European Commission, Directorate-General for International Partnerships (DG-INTPA), the European Nuclear Education Network set up a group of international experts, acting as Scientific Committee and design body for the first Specializing Master on Nuclear Safeguards, a program with an official academic recognition. The implementing agent has been identified in Politecnico di Milano, also because of its experience in educational and training programs for professionals and innovative education tools, including on-line courses.

The action from the European Commission is perfectly suited in addressing two major items in the education on nuclear safeguards: the wide and open international collaboration and the spread into the universities' program.

Under the guidance of the experts from the EU-Joint Research Centre, the Scientific Committee designed a one year, 60 ECTs equiv-

9 https://www.nuclearsafeguards.polimi.it/

alent, master for professionals, following two main directions: i) to adopt a holistic approach, looking at all the multifaceted features and challenges inherent to nuclear safeguards, from the legal aspects to the nuclear technologies, from the international socio-political environment to the scientific items; ii) to foster the set up of an international classroom of professionals, duly supporting the participation of female learners.

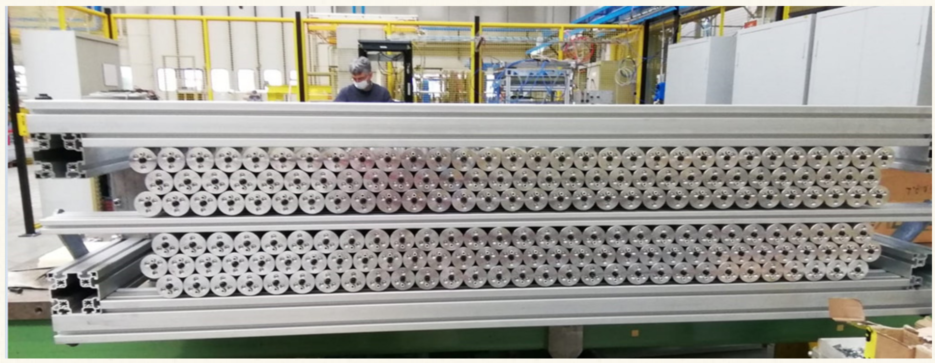
That second item was addressed, according to a specific strategy from the DG-INTPA, by offering fellowships to professionals coming from extra-EU Countries as well as specific fellowships reserved to female participants.

The strategy of a “blended” program, with on-line resources adopted at a large extent, will allow the effort produced to launch the first of the two editions of the specializing master, to be capitalized for future developments, i.e. both for the second edition and for the possible dissemination of the educational products (e.g. all the MOOCs-like video-lectures) in the EU Universities of the ENEN association. The integration of nuclear safeguards education into the classical nuclear engineering programs, being one of the key opportunities enabled by the initiative.

MUTOMCA PROJECT (MUON TOMOGRAPHY FOR SHIELDED CASKS)

Investigation of muon tomography for re-verification of spent fuel casks – Status update

by K. Aymanns
(Forschungszentrum Jülich GmbH)

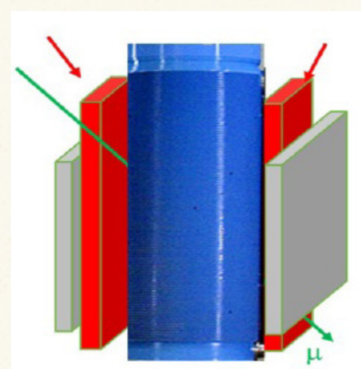


Pic. 1: Drift tube module (source: INFN)

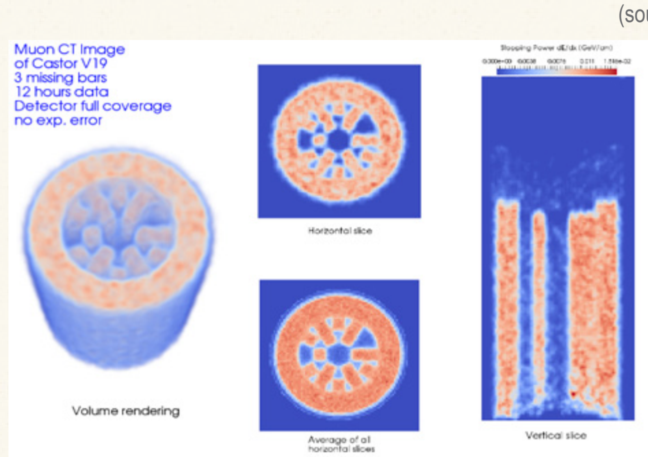
The MUTOMCA project is a multilateral collaboration among the National Institute for Nuclear Physics (INFN;Italy), the Jülich Research Center (FZJ;Germany), BGZ Company for Interim Storage (BGZ Gesellschaft für Zwischenlagerung mbH (BGZ; Germany)) and the European Atomic Energy Community (EURATOM). The goal of this 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 in case of temporary failure of monitoring systems. In this regard a muon detector based on drift tubes (picture 1) and capable of showing the interior of the shielded casks including the spent fuel has been developed by INFN and is currently under construction.

After accomplishing the detector system, it is planned to test the detector in a field trial at a Germany dry storage facility. To test the detector performance, it is foreseen to measure a partly loaded spent fuel cask, which contains 16 spent fuel assemblies and three dummy elements. Two muon detector modules will be installed in proximity of the CASTOR V19 cask (picture 2) and moved around in several measurement positions to achieve nearly 360-degree coverage of the casks.

A versatile and highly-configurable simulator has been developed by INFN, together with tools for analysis and visualization. The results of the Monte Carlo simulation for a CASTOR V19 casks with 16 spent fuel assemblies and three empty positions are shown below.



Pic. 2: Scheme of application two muon tomography detector modules in measurement position (source: INFN, BGZ)



Pic. 3: Results of Monte Carlo CT image derived from muons passing through a partially loaded spent fuel cask (source: INFN)

technical articles

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

SMALL MODULAR REACTORS AND NON PROLIFERATION: MAIN ISSUES AND PBMR EXAMPLE

by Riccardo Ferretti
(POLIMI - Politecnico di Milano, Italy)
(Participant of the 18th ESARDA Course, selected student essay)

1. Introduction

Nuclear energy will play a very significant long-term role in what will be the world's energy demand, in a frame that requires a reduction of climate impact in energy production. This process will be the result of many solutions, concerning: waste management, safety, security, economy, social acceptance and non proliferation issues. To address these challenges, small modular reactors (SMRs) can offer a valuable option. This is why many countries are involved in the development of SMRs as part of a new generation of nuclear power plants [3]. Indeed, they offer simpler, standardized, and safer modular design, require smaller initial investment and have shorter construction times. Moreover, smallsized SMRs could be transportable, could be used in isolated locations without advanced infrastructure/power grid, or could be clustered in a single site to get a larger power station. This could be highly beneficial for countries with limited electricity grid system and/or limited financial resources for investment in large nuclear power plants [5].

1.1 Why SMRs: overview and challenges

The IAEA classifies a SMR simply as a reactor having an electrical output less than 300MWe. But the concept of a Small Modular reactor goes beyond that. Indeed, SMRs are: deliberately Small, meaning a fraction of the size of a conventional nuclear power reactor, but having a tailored design; Modular, making it possible for systems and components to be factory-assembled; Reactors, meaning they are based on nuclear fission to generate heat.

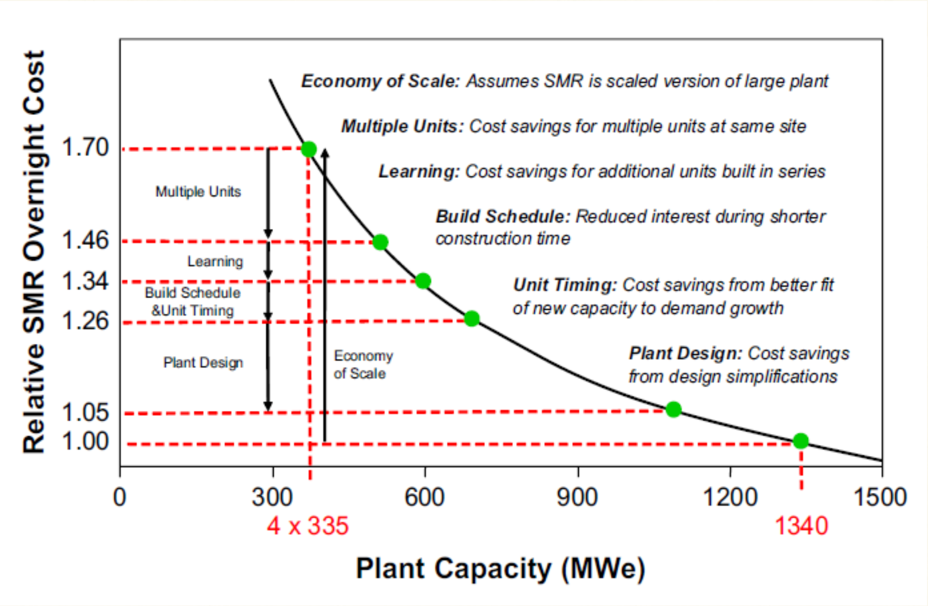


Figure 1: Economy of scale and cost reduction fo SMRs [2]

Thus, it must be pointed out how they should not be considered as merely scaled-down versions of large plant designs, but deliberately small, i.e. designs that do not scale to large sizes but rather capitalize on their smallness to achieve specific performance characteristics [2].

Vuji´c et al. point out the following advantages of SMRs [5]: (1) Power generation capabilities for remote areas difficult to access; (2) Faster, standardised and modularised construction in shops, reducing on-site work; (3) Long-life fuel cycle and reduced need for refueling; (4) Design simplification; (5) Passive safety by design; (6) Expanded potential siting options, since more sites are suitable for SMRs; (7) Smaller nuclear island and footprint of the whole nuclear power plant; (8) Lower operation and maintenance costs; (9) Lower initial costs and risks; (10) Proliferation resistance.

Among the hot topics of the development of SMRs, the economical competitiveness with respect to large plants is a crucial issue. Indeed, nuclear power economics depend on three broad types of costs: project investment, operations and maintenance, fuel and waste [10]. While the unit fuel and waste costs of SMRs are similar to those of larger reactors, big plants benefit from scaling factors: as units of a similar design increase in size, their cost rises more slowly and unit costs fall (this is well-known as the "economy of scale", EOS). This is the reason why in the last decades proven designs coming from 70s big plants have been preferred.

Nevertheless, in many circumstances the total project cost can be the dominant consideration: for capital-intensive big nuclear plants, which are now projected to cost on the order of 4–6 billion each, the initial investment tag may be prohibitively high for many potential owners, such as small countries or private utilities. In all these cases, despite of the EOS, SMRs could enable more
potential customers to enter the market and benefit from significantly lower initial costs and, thus, financial risk [2]. In addition to that, a closer look at small plants suggest that other factors can mitigate the EOS disadvantage. An example is shown in Figure 1, in which a specific assessment for a 1340MWe large plant compared to a plant comprised of four 335MWe units is presented. These findings, referring to a Westinghouse study [2], indicate that the 70% EOS penalty for the SMR plant could be reduced to a nominal 5% penalty when considering the accumulation of offsetting factors such as infrastructure sharing, accelerated learning, and design simplification.

Safety is another aspect that will play in favor of SMRs. According to Hidayatullah et al. [3], design simplification, standardization and modularization have the potential to increase the safety over existing plants, lowering failures probability. SMRs are thought to be safe by design: no large piping is connected to the vessel (so no large LOCA[1] accident is expected to happen), pumps and control rod mechanism are located inside the vessel and passive safety systems are adopted (e.g., cavity flooding system, neutron poisons injection by gravity).

Besides attractive advantages and economical analysis, the deployment of competitive small modular reactors raises also several challenges. Some relevant issues are the following: (1) Nuclear material management: spent fuel will be spread across many more sites; (2) Social acceptance and perceived risk; (3) Law instruments for design certification and licensing procedures; (4) Non proliferation issues, since much more work and pressure will be borne by control authorities[2] [5].

2. Proliferation issues

Proliferation resistance is actually a crucial driver for the development of a new generation of nuclear reactors in general. However, for SMRs it could be pointed out how specific measures are entailed: having a larger number of spread and smaller reactors means that an improved safeguards and non proliferation system is needed. So the question is how to configure the nuclear energy enterprise preventing the global dispersal of fuel cycle facilities, which handle fissile material in bulk form, while at the same time not impeding the global success of nuclear power plants, which handle fissile material only in a discrete form, amenable to item accountability (IAEA, 2005b) [12].

The most attractive solutions follow these two main branches:

1. SMRs without on site refuelling: reactors assumed to be completely factory fabricated and fuelled, or undergoing an on-site refuelling by a dedicated team service, provided by the vendor of the fuel, bringing in and taking away all fresh and spent fuel, and the refuelling equipment itself.
2. SMRs enhancing non-proliferation by design choices: for instance reactors withhigh burnup and low ^{239}Pu content in spent fuel. That is why HTGRSMRsseem to offer a very attractive solution, having high fuel burnup, thus spent fuel with a high content in ^{240}Pu, and low ratio of fissile to fuelblock/fuel-pebble mass [12].

2.1 SMRs without on-site refuelling

In line of principle, in the frame of reactors without on-site refuelling, the usercountries could relax all the fuel management on foreign suppliers, avoiding political and economic tensions with other countries, increasing the energy security and avoiding any direct obligation in waste temporary storing and final repose. All that will prevent any misuse of nuclear material, together with a reactor weld sealed over the whole operation time. Particularly, IAEA stated the essential features of small reactors without on site refuelling in early 2005 as the following [11]: (1) Capability to operate without refuelling for a reasonably long period, consistent with the plant economics and energy security; (2) Minimum inventory of fresh and spent fuel being stored at the site outside the reactor during its service life; (3) An enhanced level of safety, consistent with the scale of global deployment of such reactors, through wider implementation of inherent and passive safety features; (4) Economic competitiveness for anticipated market conditions and applications; (5) Difficult unauthorized access to fuel during the whole period of its permanence onsite and during transportation; (6) Capability to achieve higher manufacturing quality through factory mass production, design standardization and a common basis for design certification.

2.2 Technical aspects

Core access One of the main features of a proliferation resistant reactor is the core accessibility. The ideal choice is to design physically inaccessible cores, a solution which would imply necessarily SMRs without on site fuelling. Indeed, according to Prasad et al. [7], sealed reactors still make excellent targets for sabotage, and any possible attack, even an unsuccessful one, has to be avoided in the present-day political and social frame: it will cause mass panic against nuclear. Furthermore, a concrete, technical definition of what constitutes a “sealed” core is necessary, along with a better comparative assessment of the potential merits of such an arrangement to determine whether the sealibility of cores dominates potential alternative ways of increasing proliferation resistance [7] [12].

Besides that, we have conventional safeguard procedures, such as remote monitoring and security in fuel handling, inventory and accountancy, inspections and regulator control.

Last but not least, in the case of reactors without on-site refuelling, it should be pointed out how the transport of the reactor itself would entail significant challenges: it should be small enough to be transportable and fuel elements integrity and non-displacement must be ensured during the transport, withstanding the decay heat at the same time. This thermal power is, for instance in case of a conventional LWR, ≈ 10kW/tonfuel after a year. Considering that actual best dry cask technologies are able to remove up to ≈ 35kW heat per cask, the design for transportable SMRs without onsite refuelling will be restricted up to 40MW(e) (assuming the thermal efficiency to be 0.33) [7].

Fuel Looking closely to some of the projects under development (Table 2.2), it becomes clear how many of these reactors are expected to have a considerable quantity of 239Pu in spent fuel that in some cases could considered as weapons grade plutonium, whenever the amount of ^{240}Pu is under 7%[3].

Therefore, several of the SMRs under development will continue to be subjected to stringent safeguard inspections due to their fissile inventories, thus nothing substantially different from big conventional plants from this point of view. However, it is also true that SMRs are likely to benefit from easier material accountancy due to smaller inventories (only 18 fuel

1 Loss Of Coolant Accident.
2 For a more comprehensive analysis the reader is referred to Vuji´c et al.
3 ^{240}Pu has a huge probability to undergo spontaneous fission, leaving a certain probability of pre-detonation of a weapon containing a high quantity of ^{239}Pu.

assemblies, for instance, in the Japanese 10MW(e) Toshiba 4S).

Concerning core life, in general it could be asserted that SMRs usually claim core lives greater than 4 years, which is consistently longer in case of fast breeder reactors [7]. For example, referring again to the Toshiba 4S 2.2, the long core life makes possible to adopt some non-proliferation measures like, in this case, a special fuel handling equipment which will be made available at the nuclear power plant only during refueling. In addition, this fuel handling equipment will be shared between several such nuclear power plants [7]. Thus, the vendors propose that by not having the refueling equipment permanently available at the facility, the likelihood of clandestine access to core and nuclear fuel at any time is reduced dramatically.

Nevertheless, the access to nuclear fuel is not the only point to be attentioned. Indeed, long-lifetime cores would imply also design solutions requiring no core access for the maintenance of the in-vessel components for long time. This is a problem that becomes even more significant for integral designs, in which pumps and other components are located directly inside the vessel. In all these cases is therefore crucial to demonstrate the reliability in operating for such long time, without need to open the (sealed) vessel.

Breeders FBR[4] are the most suitable choice to design long life reactors, but need to include further safeguards: the abundant conversion of 238U in 239Pu could be exploited for production of weapons-grade material. Hence, fast SMR designers have thought cores such that there is no way to get the core altered to obtain breeding areas suitable to transform a power reactor to a nuclear fuel breeder [7].

3. Pebble Bed Modular Reactor

A specific kind of reactor which could be intrinsically proliferation-resistant is the pebble bed modular reactor.

Derived from designs by US and Germany in the 1970s and 1980s[5], the pebble bed modular reactor (PBMR) is thought as a small, modular reactor that is helium cooled and graphite moderated. The fuel elements, having spherical shape, are called pebbles, and are approximately the size of a tennis ball. In the last years, the PBMR has been redesigned and marketed mainly by the Republic of South Africa and China [9], coupling the high-temperature gas system to a gas turbine, achieving at the same time a very high level of passive safety without active engineered systems [4].

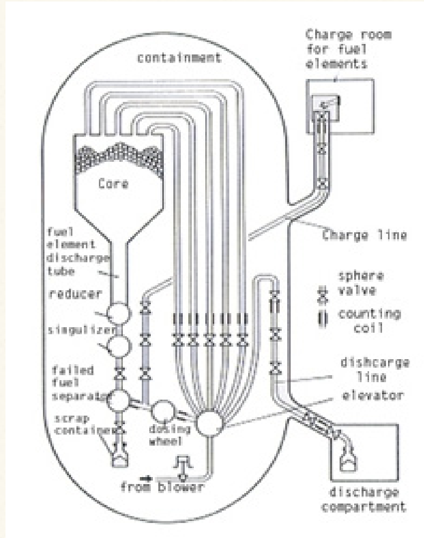


Figure 2: Scheme representing a PBMR design[9]

A scheme of the design is shown in Figure 2. When fully loaded, according to the South-Africa design (thermal power generation of 268 MW and an electrical output of 110 MW), the core would contain 310 000 fuel spheres and 110 000 graphite spheres for moderation. Helium coolant enters the reactor vessel at a temperature of approximately 500 °C and a pressure of 70 bar. Then, the helium flows down through the core, picking up the heat generated, and exits from the bottom of the reactor vessel at a temperature of approximately 900 °C [8].

3.1 Fuel

The PBMR fuel elements consist of small 6 cm spheres, or pebbles, roughly the size and shape of a tennis ball. These spheres are filled with Tristructuralistropic (TRISO) fuel in a graphite matrix: 0.5 mm diameter UO2 fuel kernels, coated with four layers: (1) carbon, (2) a dense inner layer of pyrolytic carbon (PyC)[6], (3) a ceramic layer of SiC to retain fission products at elevated temperatures and to give more structural integrity, (4) a dense outer layer of PyC.

TRISO fuel particles are designed not to crack under different stresses, such as thermal expansion or fission gas pressure, at temperatures up to and beyond 1600 degrees, thus ensuring the fuel integrity also in case of severe accidental scenarios [6]. A representation of a TRISO fuel element is given in Figure 3.

In the scheme described by Durst et al. [6], the fuel is fed into the reactor from a fresh fuel storage bin, and recirculated at least six times to optimize the burnup, at the rate of approximately 500 spheres/day (this fuelling strategy ensure to reach higher performances in terms of burnup, compared with conventional light water reactors). The spent pebbles are pinpointed thanks to gamma-ray activity measurement and then discharged and stored into spent-fuel storage bins.

Why Proliferation Resistant The PBMR fuel is ≈ 10% enriched in U-235, with a uranium content for sphere of around 9 grams. In the 165 MWe design, the reactor core would have approximately 452,000 fuel pebbles, leading approximately to 5.5 significant quantities (SQ) of U-235 in the form of lowenriched uranium (LEU) and 5.3 significant quantities of plutonium[7] [6].

Considering that the spent fuel would then be stored in bins of 62000 spheres each, it comes that, since each spent pebble would contain around 0.12 grams of Pu-239, it would be necessary to reprocess more than 50000 spheres in order to get a SQ of plutonium.

In few words, any attempt of fuel diversion should be easily detectable, since: (1) a huge

4 Fast Breeder Reactors.

5 Two operational prototypes were built: the 15 MWe AVR and the 300 MWe THTR [8].

6 This material acts as a moderator and as a porous material able to accommodate fission gases.

7 The significant quantity (SQ) is a quantity defined by IAEA, representing the amount of fissile nuclear material required to fabricate a simple bomb, accounting also for material lost in the chemical conversion and machining steps. A SQ of low-enriched uranium (U-235 under 20%) is 75 kg of U-235 in the form of LEU. An SQ of plutonium is 8 kg [6].

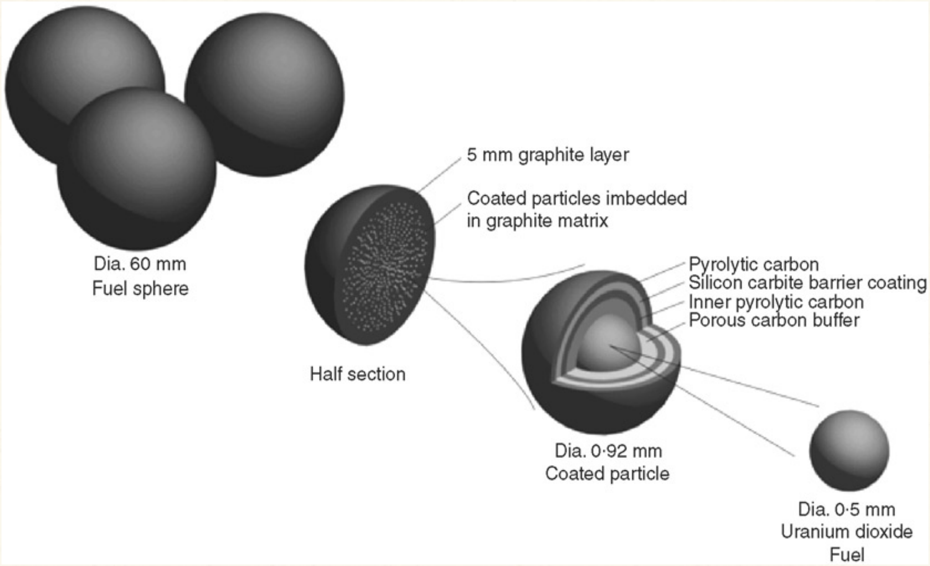


Figure 3: TRISO fuel elements structure [4]

number of fuel pebbles would be required; (2) considering the TRISO structure, the diversion of the fuel would be uneasy, requiring several manufacturing steps [6].

3.2 Safeguards approach

Even though it is promising as a "prolfera-tion-reistant", the PBMR requires tailored nuclear safeguards measures. Indeed, the reactor holds hundreds of thousands of small fuel spheres not uniquely identifiable: for this reason, it could be classified as a bulk-fuel reactor. Consequently, a traditional safeguards approach for "item facilities" is not practical. Thus, even though the IAEA has Safeguards Criteria for "Other Types of Reactors", they are not specific and do not seem appropriate for the PBMR.

Currently, the safeguard approach to the PBMR is based on maintaining the continuity-of-knowledge of the fresh, core, and spent fuel by flow monitoring and number balancing – i.e. counting the fuel pebbles that go in and out of the reactor. This approach is not ideal, since there is no technical means of recovering the continuity-of-knowledge (and closing the number balance) if the containment/surveillance systems fail. This is why a specific safeguard system for the PBMR is still under further development [6] [1].

Safeguard concerns can be summarized as the following [6]: (1) diversion of an SQ of Pu from core/spent fuel storage; (2) diversion of an SQ of 235U from fresh/spent fuel/core. Since shorter in time, the diversion of Pu is assumed as the main concern. Two possible scenarios are considered: (1) reprocessing of the fuel using a clandestine reprocessing plant or (2) irradiation of specially designed uranium targets, hidden in the normal input of the reactor. For the latter, Herring, et al., at the Los Alamos National Laboratory (LANL), estimated that altered fuel spheres, inserted into the PBMR to produce weapons grade plutonium, are likely to lower the number of spent fuel pebbles required for the diversion of an SQ of plutonium from ca. 50,000 to 20,000 [6]. In few words, for any diversion scenario a huge number of fuel pebbles would need to be processed: this is a feature that plays in favor of the intrinsic proliferation resistance of the PBMR.

Nonetheless, here are listed the main lacks in applying safeguards, arising from the peculiarity of the fuel elements [6]:

1. Any traditional core verification is actually infeasible;
2. especially during initial start-up, the reactor is full of graphite moderating spheres, gradually replaced with fuel spheres: this could be somehow misleading, since fuel diversion could be done by substituting fuel pebbles with graphite dummies;
3. spent fuel bins could contain more than 600000 pebbles: verification of the spent fuel in storage through any traditional item counting or random item identification is impractical.

For the latter, it must be pointed out how this problem is actually very similar to the monitoring of a MOX fabrication facility: in practice, as long as the IAEA has the ability to verify the bulk of the spent fuel in storage, through the use of radiation-based volume or fill-height measuring devices, the accumulation and inventory of spent fuel pebbles could be effectively monitored. As for core/spent fuel bins verification, a Bulk-Fuel Reactor Approach could be adopted, aiming at fulfilling these requirements [6]: (1) flow monitor/pebble counting for fuel input/output, to produce a MUF (accounting for broken balls, counting discrepancies,...); (2) random checks on fuel elements, using both non-destructive and destructive assays; (3) estimation of the core content by means of power output records and other operational data; (4) Containment, surveillance and sealing measures; (5) advanced non-destructive assays to monitor spent fuel bins. It comes how an hybridized and "layered" approach is required, employing fuel flow monitoring, redundant advanced containment and surveillance, together with bulk nuclear material accountancy and verification techniques [6].

Conclusion

In conclusion, it could be asserted that the PBMR represents an attractive small modular reactor, merging potential proliferation resistance together with high performances, in terms of fuel burnup, passive safety, core lifetime, and plant thermal conversion[8]. It is moreover a good example showing how many challenges emerge in applying existing safeguards to the Small Modular Reactors enterprise.

8 Gas cooling enable higher temperatures than water-cooling, hence higher thermal efficiency.

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