Supporting the Additional Protocol declarations on nuclear research and technology by the JRC TIM DU platform

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Abstract

Research subject to dual-use trade controls may play an important role in proliferation programmes because the exchanges among research entities are traditionally open and prone to be exploited by third countries' illicit developments.

For these reasons, apart from information "in the public domain" or "basic scientific research", transfers of nuclear technology are subject to export authorisation requirements and government-to-government assurances like the export of tangible goods, as specified by the Nuclear Suppliers Group's guidelines and national export control laws.

Also the requirements of the Model Additional Protocol to the Agreement(s) between States and the International Atomic Energy Agency for the Application of Safeguards include declarations about national research and development activities related to the nuclear fuel cycle, but do not require declarations of technology transfers to third countries.

The European Commission JRC, in collaboration with Liege University, has developed the Tools for Innovation Monitoring Dual-use (TIM DU) platform that can facilitate the identification of entities publishing research with a dual-use potential in the various countries. Together with many dual-use goods and emerging technologies, TIM DU maps nuclear-fuel cycle activities' results included in scientific abstracts, patents, and EU-funded projects, allowing analysts to gather lists of documents, geographical distributions, collaborations, and authors related to these activities.

These results can help the national authorities submitting declarations to IAEA in accordance with Additional Protocol's Article 2.a, both to identify also previously unknown national research actors and their collaboration networks, as well as to raise the awareness of national research entities about potential sensitivities with external collaborators. The IAEA could also use TIM DU to support the verification of the completeness and correctness of the declarations concerning nuclear fuel cycle research.

Keywords: export control; nuclear safeguards; non-proliferation; dual-use; research; strategic trade; intangible technology transfers.

1. Research and technology

Research is essential to support technological development as well as education. It is usually divided into fundamental - more typical of the academic sphere - and applied, in support to industry. This distinction is however not so clear-cut, especially considering the increasing collaborations between academia and industry, which will be discussed when analysing the TIM DU results in the second part of this article [1, 4].

Various actors are involved in research, ranging from universities to research and development organisations, as well as governmental agencies, industries, consulting companies, and even hospitals.

Research can share technological developments in multiple ways, primarily involving intangible technology transfers (ITT) through international projects and collaborations, exchanges of researchers, training, technical assistance, and scientific publications [5].

Transfers of sensitive dual-use technology are subject to export controls, both from the civil and the military side, respectively represented in the EU by the so-called "EU Dual-use Regulation" (i.e. EC Regulation 428/2009, about to be Recast in 2021 [6,7]) and the EU Common Military List.

Export control of ITT is particularly challenging because they are difficult to monitor and stop, as there is no crossing of borders of physical goods.

The EU Dual-use Regulation contains in its Annex I the dual-use items, definitions, and various decontrol notes deriving from the Nuclear Suppliers Group - as well as the Wassenaar Arrangement, Missile Technology Control Regime, Australia Group, and the Chemical Weapons Convention [8-12], integrated into the annually amended Commission Delegated Regulation [13].

The definitions used are therefore essentially the same both in the Dual-use Regulation and the Nuclear Suppliers Group, which will be considered as references in this paper, in particular referred to nuclear technology.

2. Important definitions related to dual-use research controls

According to the EU Dual-use Regulation, 'dual-use items' shall mean items, including software and technology, which can be used for both civil and military purposes, and shall include all goods which can be used for both non-explosive uses and assisting in any way in the manufacture of nuclear weapons or other nuclear explosive devices.

Dual-use technology is the specific knowledge or information needed for the development, production or use of dual-use goods. Together with software, it is hence subject to export controls just like tangible goods, such as systems, equipment, components; test, inspection and production equipment; or materials.

Technology can take the form of technical assistance or technical data.

2.1 Technical data

Technical data include blueprints, models, formulae, tables, engineering designs and specifications, manuals and instructions written or recorded on media or devices.

The approval of any dual-use item for export also authorises the export to the same end-user of the minimum "technology" required for the installation, operation, maintenance, and repair of the item.

Important to notice is that according to the Nuclear Suppliers Guidelines and the EU Regulation, controls on "technology" transfer do not apply to information "in the public domain"[1] or to "basic scientific research"[2].

These are key decontrol notes that, save verification of their actual relevance, may apply to most research activities, making them not subject to export authorisations and traceability requirements.

Compliance by organisations engaged in research subject to dual-use controls is a topic of increasing concern. To assist researchers, the EU is about to issue a Commission Recommendation tailored to the needs of academic and research communities, providing guidance for implementing internal compliance controls in different research settings. The draft of the Recommendation was supported by a public consultation of all concerned stakeholders (e.g. academia and research institutions) that was closed on 30 November 2020 [14]. This follows a previous Commission Recommendation dedicated to dual-use suppliers in general [15].

2.2 Technical assistance

"Technical assistance" includes instructions, skills, training, working knowledge, consulting services and may involve the transfer of technical data.

Also the provision of technical assistance and associated technology transfer to third countries is subject to national authorisation.

The Dual-use Regulation's recast expected in 2021 will directly include technical assistance, not only provided abroad but also to third country's nationals "temporarily present in the customs territory of the Union" [7].

Technical assistance is also an activity performed by the IAEA itself through its Technical Cooperation programme with third countries [16].

3. Strategic export control and nuclear safeguards

After this preamble about dual-use research, it is important to briefly recall that, as already described in [17], strategic export control is a barrier against proliferation called for by United Nations Security Council Resolution 1540 [18], aiming at preventing unauthorised access to strategic technology and goods.

Export control and nuclear safeguards developed in parallel, as two intimately linked elements of the non-proliferation framework. This link is evident in both the Non Proliferation Treaty [19] and the Nuclear Suppliers Group (NSG) Trigger List guidelines [20]:

- The Non Proliferation Treaty's Art. III.2., conditions the export of equipment or material especially designed or prepared for the processing, use or production of special fissionable material to any non-nuclear-weapon State to international nuclear safeguards;[3]
- The Nuclear Suppliers Group's Trigger List guidelines state that safeguards are a condition of supply for nuclear goods [20, Art. 4].

1 "Technology" or "software" that has been made available without restrictions upon its further dissemination.

2 Experimental or theoretical work undertaken principally to acquire new knowledge of the fundamental principles of phenomena and observable facts, not primarily directed towards a specific practical aim or objective.

3 Similar obligations are provided for in regional non-proliferation treaties (e.g. the Tlatelolco Treaty, the Rarotonga Treaty, the Bangkok Treaty and the Pelindaba Treaty), EURATOM.

The "NSG Guidelines for transfers of nuclear-related dual-use equipment, materials, software and related technology", containing in annex the Dual-Use List (DUL) [21] were developed after the discovery of undeclared proliferation activities in Iraq in 1991. This determined also another turning point in the international safeguards framework, leading to the introduction in 1997 of the "Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards" (AP - INFCIRC/540) [22].

This event highlights the complementarity between the IAEA safeguards system and strategic export controls. Thanks to more comprehensive States' reports and inspections, the IAEA can obtain a better insight into a State's nuclear fuel cycle-related activities and capabilities [23-25]. Yet, this does not include the control of nuclear exports, which is of course left to the states, organised - or not – according to principles and control lists set by multilateral arrangements such as the NSG [26].

The controls set by the NSG and other export control regimes on technology needed for the development, production or use of WMD are as important, or even more important, than strategic commodities themselves because technology is critical to the use of the controlled goods and the development of indigenous WMD-related production capabilities, as the A.Q. Khan proliferation case demonstrated [17 5, 6, 2].

4. Nuclear Suppliers Group and technology controls

Most of the provisions of the NSG guidelines are incorporated into the EU Regulation, it is however interesting to comment on those related to technology.

The NSG Part 1 guidelines speak extensively of technology, as e.g. "facility, or equipment or technology therefor".

The same applies to NSG Part 2 guidelines, mentioning "equipment, materials, software, and related technology".

According to both Nuclear Suppliers Group guidelines, "Technology" directly associated with any controlled item will be subject to as great a degree of scrutiny and control as will the item itself, to the extent permitted by national legislation.

In addition to controls on "technology" transfer for nuclear non-proliferation reasons, suppliers should promote protection of technology for the design, construction, and operation of trigger list facilities in consideration of the risk of terrorist attacks, and should stress to recipients the necessity of doing so.

5. Model Additional Protocol's requirements

The Additional Protocol (AP) [22] expanded the set of information that States are required to transmit to the Agency under their report¬ing obligations and expanded the verification toolkit at the IAEA disposal to exclude the presence of possible unde¬clared nuclear material and activities in a State.

5.1 Additional Protocol and nuclear research

While INFCIRC 153 does not make any reference to technology and research, the AP does not explicitly refer to nuclear technology, but implicitly includes technology in connection to the provision of information about research activities, or – indirectly - description about facilities, sites and locations, as important indicators of the overall country's potential and declared list of activities.

The Additional Protocol's Article 2.a. requires that States:

> *....... shall provide the Agency with a declaration containing:*
>
> (i) A general description of and information specifying the location of nuclear fuel cycle-related research and development activities not involving nuclear material…
>
> 2.a.(i) allows the IAEA to get information about research activities which could also involve technology subject to export control provisions.

Important to note are also AP art. 2.a.(x)'s requirements to provide:

> (x) General plans for the succeeding ten-year period relevant to the development of the nuclear fuel cycle (including planned nuclear fuel cycle-related research and development activities) when approved by the appropriate authorities

And art. 2.b.(i) concerning the provision to the Agency of:

> (i) A general description of and information specifying the location of nuclear fuel cycle-related research and development activities not involving nuclear material which are specifically related to enrichment, reprocessing of nuclear fuel or the processing of intermediate or high-level waste containing plutonium, high enriched uranium or uranium-233… that are carried out anywhere in .... but which are not funded, specifically authorized or controlled by, or carried out on behalf of, ...

Article 18 illustrates the research areas of interest mentioned throughout the Additional Protocol:

a. Nuclear fuel cycle-related research and development activities means those activities which are specifically related to any process or system development aspect of any of the following:

- conversion of nuclear material,
- enrichment of nuclear material,
- nuclear fuel fabrication,
- reactors,
- critical facilities,
- reprocessing of nuclear fuel,
- processing (not including repackaging or conditioning not involving the separation of elements, for storage or disposal) of intermediate or high-level waste containing plutonium, high enriched uranium or uranium-233

Echoing the NSG guidelines, also the AP specifies that these activities do not include activities related to theoretical or basic scientific research, or to research and development on industrial radioisotope applications, medical, hydrological and agricultural applications, health and environmental effects and improved maintenance.

5.2 Additional Protocol Annex I

A key requirement in article 2.a is the provision of:

> *(iv) A description of the scale of operations for each location engaged in the activities specified in Annex I to this Protocol.*

Where Annex I lists fifteen key manufacturing steps in the nuclear fuel cycle:

i. The manufacture of centrifuge rotor tubes or the assembly of gas centrifuges.

ii. The manufacture of diffusion barriers.

iii. The manufacture or assembly of laser-based systems.

iv. The manufacture or assembly of electromagnetic isotope separators.

v. The manufacture or assembly of columns or extraction equipment.

vi. The manufacture of aerodynamic separation nozzles or vortex tubes.

vii. The manufacture or assembly of uranium plasma generation systems.

viii. The manufacture of zirconium tubes.

ix. The manufacture or upgrading of heavy water or deuterium.

x. The manufacture of nuclear grade graphite.

xi. The manufacture of flasks for irradiated fuel.

xii. The manufacture of reactor control rods.

xiii. The manufacture of criticality safe tanks and vessels.

xiv. The manufacture of irradiated fuel element chopping machines.

xv. The construction of hot cells.

Besides being captured by the requirement of art. 2.a.(i), R&D and university sites - or other actors outside the specific facilities - might also be relevant to the declarations under art. 2.a.(iv) because of their involvement in research supporting the actual manufacturing activities, i.e. “technology” for the “development, production or use” of controlled items. To acquire a more comprehensive overview of information suitable for the AP declarations, it is therefore useful to analyse also research publications related to these activities. This may also bring to the attention of the authorities unknown relevant national research actors, which could be contacted to raise their awareness about the risk of sensitive technology transfers involved in international research collaborations.

5.3 Additional Protocol Annex II

The AP also requires export declarations of items listed in its Annex II.

Art. 2.a.(ix) of the AP requires that States:

> *…shall provide the Agency with a declaration containing the following information regarding specified equipment and non-nuclear material listed in Annex II:*
>
> *For each export: the identity, quantity, location of intended use in the receiving State and date … of export;*
>
> *Upon specific request, confirmation as importing State of information provided by another State concerning the export of such equipment and material.*

Annex II lists the items contained in the NSG Trigger List (INFCIRC 254/Part 1) available in 1995 (Rev. 2). Unfortunately, AP Annex II list has not been amended thereafter, unlike the NSG Trigger List, amended already several times (the current version being Rev. 14 of 2019). This omission creates discrepancies to exporters and authorities which is addressed in various practical ways as outlined in [23,26].

More relevant to the scope of this paper, is also the fact that Annex II refers only to EQUIPMENT AND NON-NUCLEAR MATERIAL and not to "technology" (except for one occurrence). It is therefore strictly limited to tangible items, unlike the NSG "Guidelines for the Export of Nuclear Material, Equipment and Technology" which already in 1995 extensively referred also to "technology".

5.4 Comments to this section

According to the Model Additional Protocol, the information about technology required to be reported to the IAEA is hence limited to the information provided under art. 2.a. and possibly also associated to Annex I's activities, as well as art. 2.b.(i).

Although the availability of technology (and software to model, assist the processes) may be described in association to AP Annex I's list of indigenous activities, their transfer to third country's entities is not due to be declared to IAEA. There is therefore an inconsistency and distortion with respect to the national export control systems and the NSG guidelines. Moreover, the extent of research activities within the specific country, which must be described to IAEA, may also involve international collaborations and hence technology transfers which could be captured by scientific documents, and which might not be reported in States' declarations.

The verification of the completeness and correctness of the declarations to the IAEA is an important element of the analyses and inspection activities leading to the conclusion about the absence of undeclared activities.

From the IAEA's verification perspective, it would therefore be useful also to analyse the research publications related to the AP Annex I's list of activities, as well as Annex II's items. This may bring additional information about relevant research actors, as well as their possible international research collaborations.

6. TIM Dual-use

TIM Dual-Use is a web-based platform focused on dual-use research developed by the European Commission Joint Research Centre in collaboration with the European Studies Unit of the University of Liège [27].

It is part of the broader Tools for Innovation Monitoring (TIM) developed by the Joint Research Centre to support policy-making in the European Institutions in the field of innovation and technological development.

The TIM DU's database contains three types of documents:

- All the scientific publications contained in SCOPUS, which is the largest abstract and citation database of peer-reviewed literature, covering over 45 million publications in all languages provided that at least the title and the abstract are written in English;
- World-patents from the European Patent Office PATSTAT, covering more than 22 million patents issued by more than 90 patent authorities, including all the major countries, published in English;
- all EU - funded research projects throughout various research Framework Programmes, retrieved from the CORDIS web-site.

The documents date back to 1996, and the database is regularly updated twice a year.

TIM DU has been designed to map scientific abstracts, patents and EU-funded projects against the EU dual-use control list, including of course the nuclear-fuel cycle activities under Category 0.

The data are retrieved on the basis of queries combining keywords related to the controlled items, which are searched in some specific fields, such as the title, the text of the article abstracts, the authors or the organisations' name. Boolean operators (AND, OR, NOT) connect these terms to maximise the number of meaningful results and minimise the irrelevant ones.

TIM DU presents the results and the associated information in various formats, such as connectivity network charts, heatmaps, tables, bar graphs, lists of relevant documents (linked to the original sources, e.g. journals, in which case the access to the full paper depends on the user subscriptions), organisations with their geographical distributions and even authors' names.

A module based on disambiguation algorithms, called Entity Matcher, is applied in order to associate the organisations' names to a location (e.g. in case of an umbrella organisation or daughter companies is the headquarter or the most frequent location in the data that characterises the geographical affiliation), to harmonize the information of the various databases (Scopus, Patstat, and Cordis), as well as to adjust duplicates and mistakes which are sometimes present in the original data of these databases. In addition to that, any residual error can be reported to the TIM administrators and manually fixed.

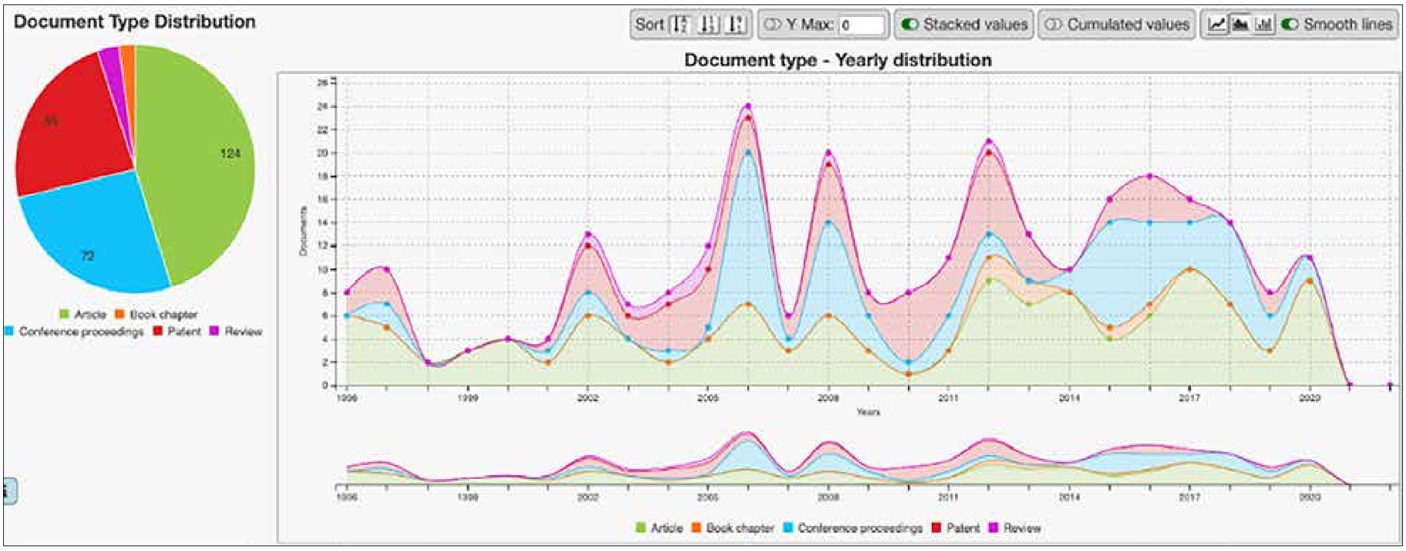

Figure 1: Type of activities related to (i) Gas centrifuges and their evolution over time.

7. TIM DU analyses of AP Annex I activities

The analysis that follows is based on the mapping of some of the fifteen key nuclear fuel cycle-related activities listed in Annex I to the Model Additional Protocol. The results presented are only a fraction of the data collected by TIM DU, considering the limits and the purpose of this paper.

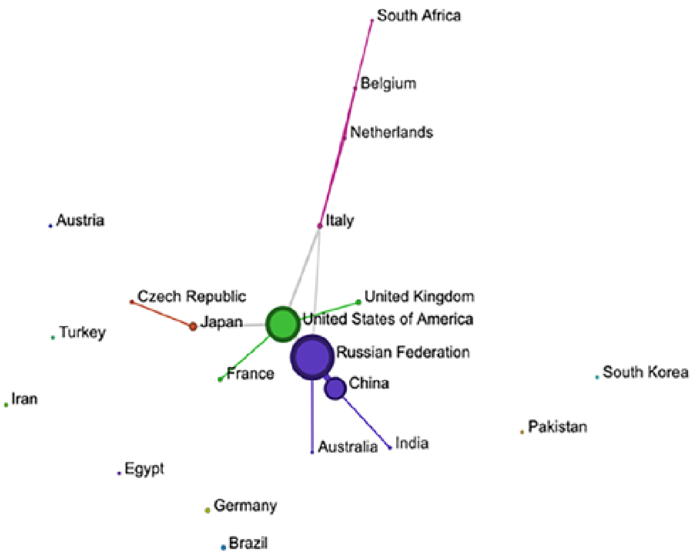

Figure 2: Countries involved in activities related to (i) Gas centrifuges

(i) The manufacture of centrifuge rotor tubes or the assembly of gas centrifuges

This paragraph will focus on the research activities and associated technology relative to the manufacture of centrifuge rotor tubes or the assembly of gas centrifuges.

Type of activities

On the basis of the constructed query, TIM Dual-Use retrieved 485 documents. The graph below shows the type of activities carried and their evolution over time between 1996 and 2020.

Around 38% of the activities are scientific publications, 34% patents, and 28% conference proceedings. No EU-funded projects were retrieved by TIM Dual-Use on the basis of our query.

Involved countries

These documents were produced by entities based in the following 21 countries: Australia, Austria, Belgium, Brazil, China, Czech Republic, Egypt, France, Germany, India, Iran, Italy, Japan, Netherlands, Pakistan, Russian Federation, South Africa, Republic of Korea, Turkey, United Kingdom, and United States of America.

Russia is the leading country with 84 documents associated (35 articles, 30 conference proceedings and 19 patents), whereas the United States, the country with the 2nd largest number of documents, presents mainly scientific publications, with only 2 patents dating back to the '90. China, with 40 associated documents, is the third most active country with 23 articles, 13 conference proceedings, and 4 recent patents.

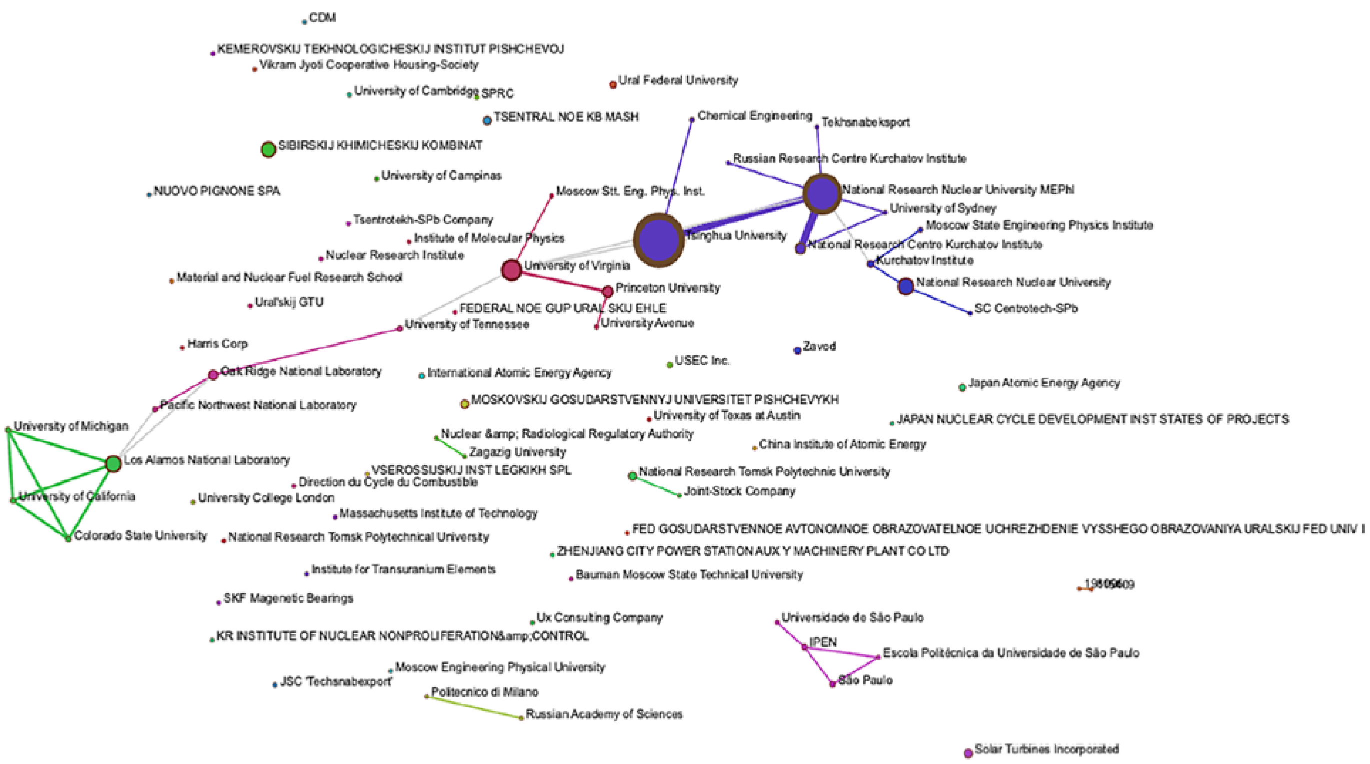

Figure 3: Organisations involved in activities related to (i) Gas centrifuges.

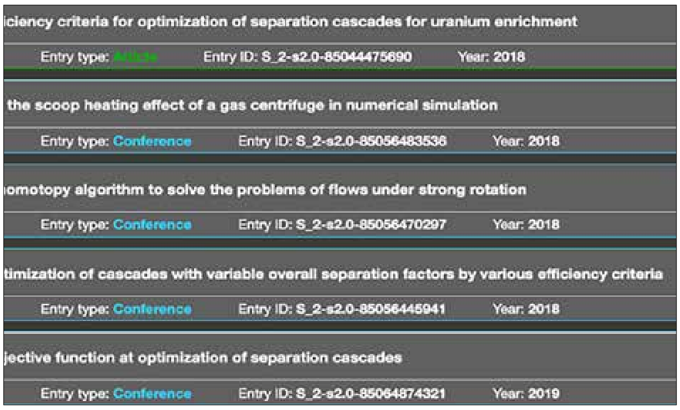

Figure 4: Collaborations between MEPhI and Tsinghua University

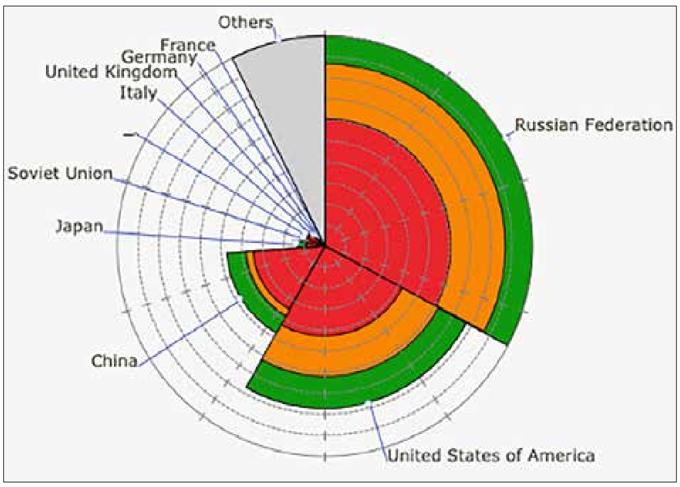

Figure 5: Countries' collaborations

Top 10 involved organisations and their international scientific collaborations

TIM DU identified more than 300 organisations undertaking research & development activities related to gas centrifuges. Among them the top 10 are:

1. National Research Nuclear University MEPhI (Russia);
2. Tsinghua University (China);
3. University of Virginia (USA);
4. Los Alamos National Laboratory (USA);
5. Siberian Chemical Combine - Sibirskij Khimicheskij Kombinat (Russia);
6. Princeton University (USA);
7. National Research Centre Kurchatov Institute (Russia);
8. Oak Ridge National Laboratory (USA);
9. National Research Tomsk Polytechnic University (Russia);
10. Tsentralnoe Konstruktorskoye Byuro Mashinostroyeniya - Design Bureau for Special Machine-Building (Russia).

It is interesting to note that China, and to a lesser extent also Russia, displays a high level of concentration of the activities, carried out by a few organisations, with Tsinghua University at the top.

TIM DU identifies Russia as the most active country and China as its main partner. The National Research Nuclear University MEPhI, the most active organisation, shares five collaborations with the Tsinghua University (China), the second most active organisation.

The collaborations are quite recent, dating from 2018 to 2019, and they concern the optimization of separation cascades for uranium enrichment and the scoop heating effect of a gas centrifuge in numerical simulation. It's also interesting to note that the authors of the publications are almost always the same ones.

MEPhI also collaborated twice with the University of Virginia (USA) even though it dates back to 1999 and 2008. Once again, the authors are the same in both publications, noticing as well that the two Russian authors are also the same ones collaborating with China, even though this time the research focused on the separation of multi-isotope mixtures. The last international collaboration of MEPhI is with the University of Sidney (Australia), an article published in 2020 exploring a new type of plasma centrifuge for isotope separation.

In addition to the collaborations with the MEPhI, the Tsinghua University co-published a study with the University of Virginia (USA) in 2015 on the simulation of the feed, withdrawals, and scoops in the flow field of a gas centrifuge by using Onsager's pancake.

Besides the publications with the MEPhI and Tsinghua University, the University of Virginia has also led a joint study with the Saclay Nuclear Research Centre (France) on the optimization of separative performance using the hypothetical gas centrifuge parameters of the so-called "Iguacu machine". Also here, the American author is still the same one.

Zeng S.	27
Borisevich V.D.	23
Wood H.G.	15
Sulaberidze G.A.	15
Bogovalov S.V.	14
Tronin I.V.	13
Smirnov A.Y.	10
Ying C.	9
Jiang D.	9
VODOLAZSKIKH VIK...	8

Figure 6: Top 10 authors' names

The rest of the scientific collaborations of the other organisations, all took place at the national level.

Top 10 authors' names

TIM DU not only can tell which author worked on a topic and with whom, it can also gather all the documents data and elaborate a list of the authors or inventors in order of their level of activity, showing on how many documents they participated. Figure 7 is an extract of the top 10 authors/inventors' names.

(iii) The manufacture or assembly of laser-based systems

Types of activities

For the research activities related to (iii) Laser-based isotopes separation, TIM DU retrieved 68 documents, which might be indicative of a lesser interest in the topic. This

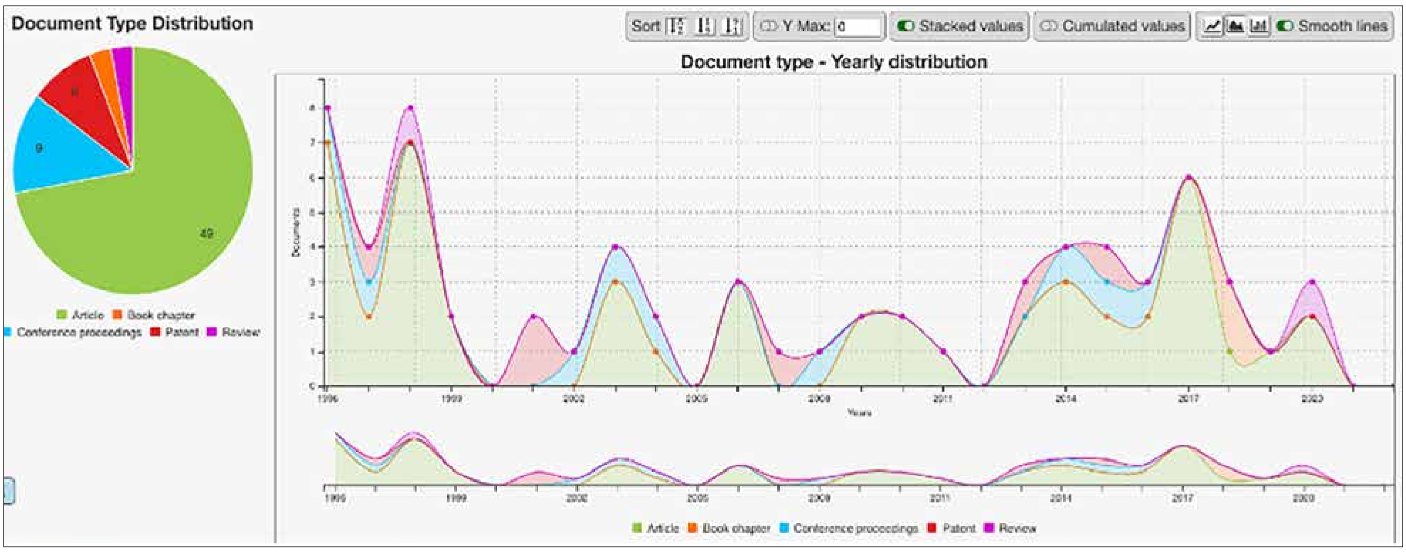

Figure 7: Types of activities related to (iii) Laser-based isotopes separation

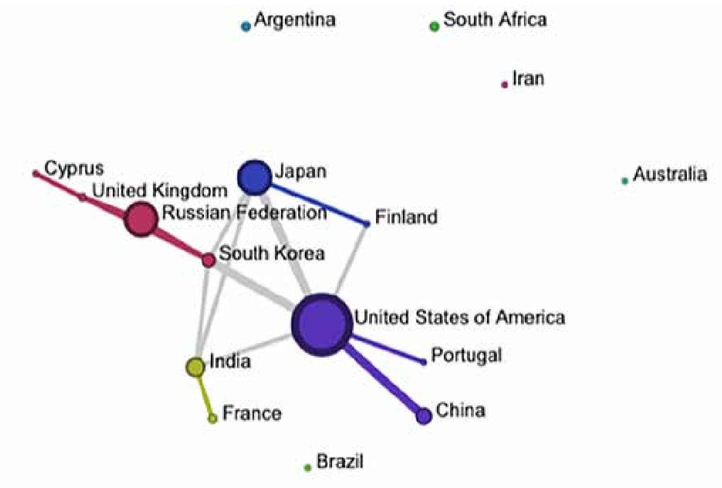

Figure 8: Countries involved in activities related to (iii) Laser-based isotopes separation

consideration might be even more applicable for other activities listed in Annex I to AP, such as the ones related to electromagnetic isotope separators, aerodynamic separation nozzles or vortex tubes, or uranium plasma generation systems. For these topics, TIM DU suggests an even lower level of activity.

Among these 68 documents, the outright majority are scientific articles, while no EU-funded project was found.

Involved countries

TIM DU identified 18 countries as being involved in research and development activities related to (iii)

Laser-based isotope separation: Argentina, Australia, Brazil, Canada, China, Cyprus, Finland, France, India, Iran, Israel, Japan, Portugal, Russian Federation, South Africa, South Korea, United Kingdom, United States of America.

Among these countries, only Japan and the United States own patents.

Top 10 involved organisations

TIM Dual-Use identified more than 70 organisations. Among them the top 10 are:

1. Russian Academy of Sciences (Russia);
2. University of Missouri (USA);
3. University of California (USA);
4. Lawrence Berkeley National Laboratory (USA);
5. University of Michigan (USA);
6. Inst. of Phys. and Chemical Research (Japan);
7. Power Reactor and Nuclear Fuel Development Corporation (Japan);
8. Pacific Northwest National Laboratory (USA);
9. Bhabha Atomic Research Centre (India);
10. Pennsylvania State University (USA).

The Russian Academy of Sciences is at the first place with nine scientific publications, followed by the University of Missouri with three. However, the Russian Academy of Sciences seems to have only national collaborations, namely with the Troitsk Institute for Innovation and Fusion Research and the company ‘Lad’ Research and Production Association.

Whereas, the University of Missouri co-published a study in 2010 with the Korea Atomic Energy Research Institute on the separation of gaseous molecules in supersonic free jets by laser-assisted selective condensation repression.

The University of California realized two joint studies in 2013, one with the South China University of Technology and one with the Bhabha Atomic Research Centre, both focusing on laser ablation molecular isotopic spectrometry.

While the Lawrence Berkeley National Laboratory co-published with the Spanish Instituto Tecnológico e Nuclear in 2009 a study on the laser synthesis of uranium oxide anions in the gas phase, and in 2015 collaborated with the Ocean University of China on a zirconium isotope analysis using laser ablation molecular isotopic spectrometry. In 2017 the American Laboratory published a joint study with the Korea Institute of Nuclear Safety focusing on uranium optical isotopic analysis in laser induced plasma spectrometry.

The rest of the scientific collaborations were all with national partners.

(x) The manufacture of nuclear grade graphite

Type of activities

Among the 273 documents almost 80% consist in articles and conference proceedings retrieved from SCOPUS, while the rest are patents, with the exception of a single EU project. In fact, as the connectivity graph of the organisations will show, a significant part of the entities are companies.

Involved countries

TIM DU lists 32 countries as involved in activities related to (x) Nuclear grade graphite: Argentina, Australia, Austria, Brazil, Bulgaria, China, Denmark, France, Germany, Greece, Hong Kong, India, Indonesia, Iran, Italy, Japan, Lithuania, Luxembourg, Pakistan, Poland, Romania, Russian Federation, Saudi Arabia, Singapore, South Africa, South Korea, Spain, Taiwan, Turkey, Ukraine, United Kingdom, United States of America.

The United States ranks at the first place with 86 documents, consisting of scientific publications and participation in the EU-funded project.

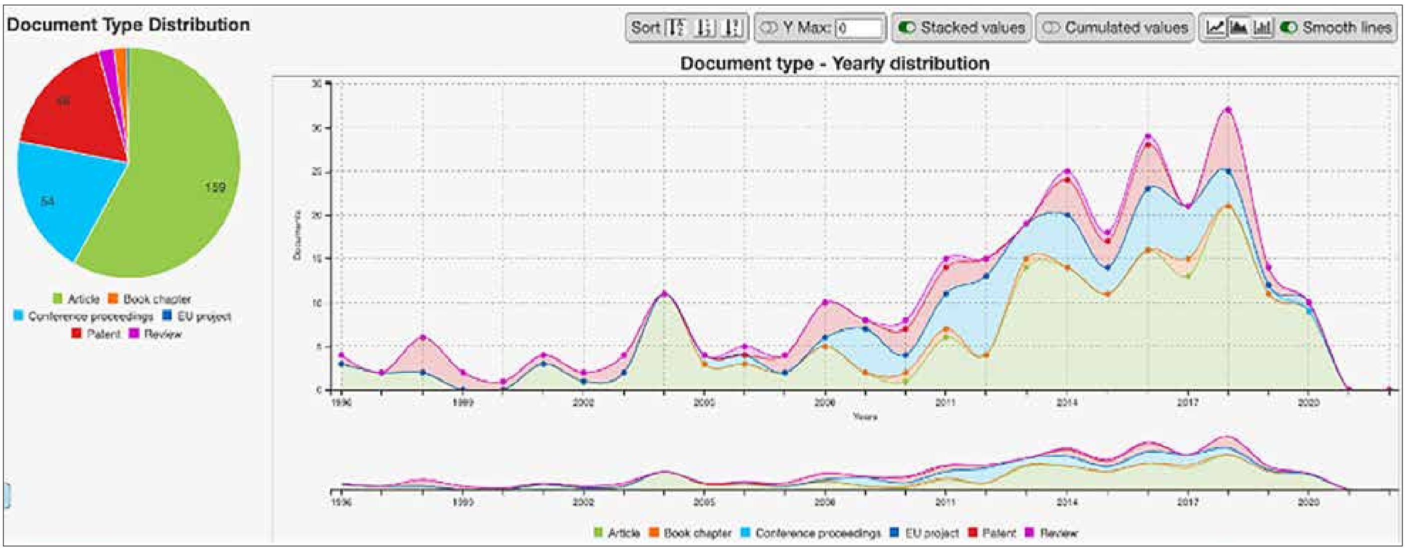

Figure 10: Type of activities related to (x) Nuclear grade graphite

The connectivity graph particularly highlights some strong connections between the country and the United Kingdom, Japan and the Republic of Korea.

Top 10 involved organisations

The organisations identified by TIM DU as being the most active in activities related to (x) nuclear grade graphite are:

1. Tsinghua University (China);
2. Idaho National Laboratory (USA);
3. University of Manchester (UK);
4. Oak Ridge National Laboratory (USA);
5. Korea Atomic Energy Research Institute (Rep. of Korea);
6. University of Missouri (USA);
7. Chinese Academy Of Sciences (China);
8. University of Oxford (UK);
9. University of New Mexico (USA);
10. University of Bristol (UK).

The Tsinghua University had an international scientific collaboration with the University of Hong Kong and University of Minnesota. In 2013 they co-published a study on the fracture properties of two types of nuclear-grade graphite, the Japanese IG11 graphite and Chinese NG-CT-01 graphite. While more recently in 2019, it realized a joint study with the Tokyo Institute of Technology on the kinetic recovery process of low dose neutron-irradiated graphite.

The second most active organisation is the American Idaho National Laboratory. In 2015 it co-published an experimental investigation of the cross flow of the Prismatic Modular Reactor (PMR) with the Seoul National University and Hanyang University.

In 2017 the Laboratory realized a study with the Helmholtz Research Centre (Germany) and University of Leeds (UK) on the neutron irradiation-induced structural changes in nuclear grade graphite types PCEA and PCIB.

While in 2020, it published an article in collaboration with the European Commission JRC based in Karlsruhe (Germany), the Royal School of Mines (UK) and the company EDF Energy Nuclear Generation Ltd (UK) investigating the thermal properties of unirradiated nuclear grade graphite between 750 and 2500 kelvin.

At the third place stands the University of Manchester, which realized in 2011 a joint study with the University of Cape Town (South Africa) and University of Oxford analysing the damage, crack growth and fracture characteristics of nuclear grade graphite using the double torsion technique.

In 2013, it published a study realized with the Celâl Bayar University (Turkey) and still the University of Oxford on the flexural strength and defect behaviour of polygranular graphite under different states of stress.

In 2020 the British University also participated in an EU funded project along with other European organisations from Spain, France, Italy and Lithuania aiming at studying innovative tools for the dismantling of graphite moderated nuclear reactors.

The Oak Ridge National Laboratory collaborated several times with the Japanese Tokai Carbon Co. Ltd.. In 2011 they published along with the Japan Atomic Energy Agency a conference proceeding on the development of new nuclear grade graphite (Fine-grained isotropic graphite) for

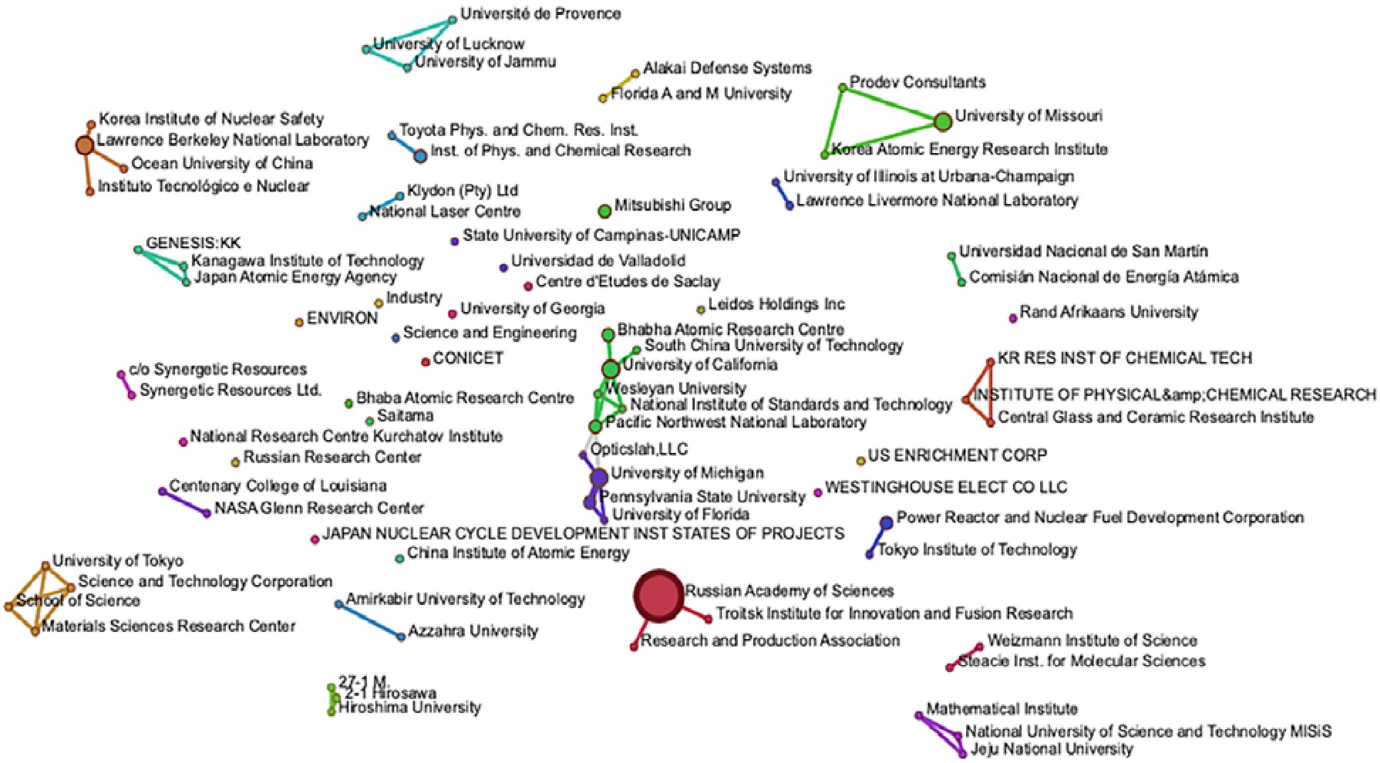

Figure 11: Countries involved in activities related to (x) Nuclear grade graphite

application to Very High Temperature Reactor (VHTR). In 2013 they published another conference proceeding, a microstructural analysis of nuclear grade graphite materials. While in 2016 they co-published an article analysing the property changes of g347a graphite due to neutron irradiation.

In 2011, the Oak Ridge National Laboratory also collaborated with the Korea Atomic Energy Research Institute, they co-published a study on the characterization of tensile strength and fracture toughness of nuclear graphite nbg-18 using subsize specimens.

In addition to the collaboration with the Oak Ridge National Laboratory in 2011, the Korea Atomic Energy Research Institute also collaborated with the Japan Atomic Energy Agency in 2013, publishing a study on the oxidation behaviour and property degradation of nuclear-grade c/c composites oxidized in air.

Besides the publications with the University of Cape Town and Celâl Bayar University realized along with the University of Manchester, the University of Oxford, co-published in 2017 a study on damage tolerance of nuclear graphite at elevated temperatures with the University of Bristol (UK), the American Lawrence Berkeley National Laboratory, University of California, and the Australian School of Mechanical and Manufacturing Engineering.

(xii) The manufacture of reactor control rods

Type of activities

The constructed query resulted in 1980 documents, with the peculiarity of having more than half of them constituted by patents, distributed almost homogeneously over the years.

Both the amount of results and their distribution over time suggest an active interest on the technology associated to the topic.

Involved countries

TIM DU detected the involvement of 51 countries in the research and development activities related to (xii) Reactor control rods: Argentina, Australia, Austria, Bangladesh, Belgium, Brazil, Bulgaria, Canada, China, Croatia, Czech Republic, Egypt, Finland, France, Georgia, Germany, Ghana, Greece, Hong Kong, Hungary, India, Indonesia, Iran, Italy, Japan, Jordan, Lithuania, Malaysia, Mexico, Netherlands, Nigeria, Norway, Pakistan, Poland, Romania, Russian Federation, Saudi Arabia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Syria, Taiwan, Turkey, Ukraine, United Kingdom, United States of America.

However, taking into consideration only the patenting activities, the map limits the number of countries to fifteen (see figure 16 here below).

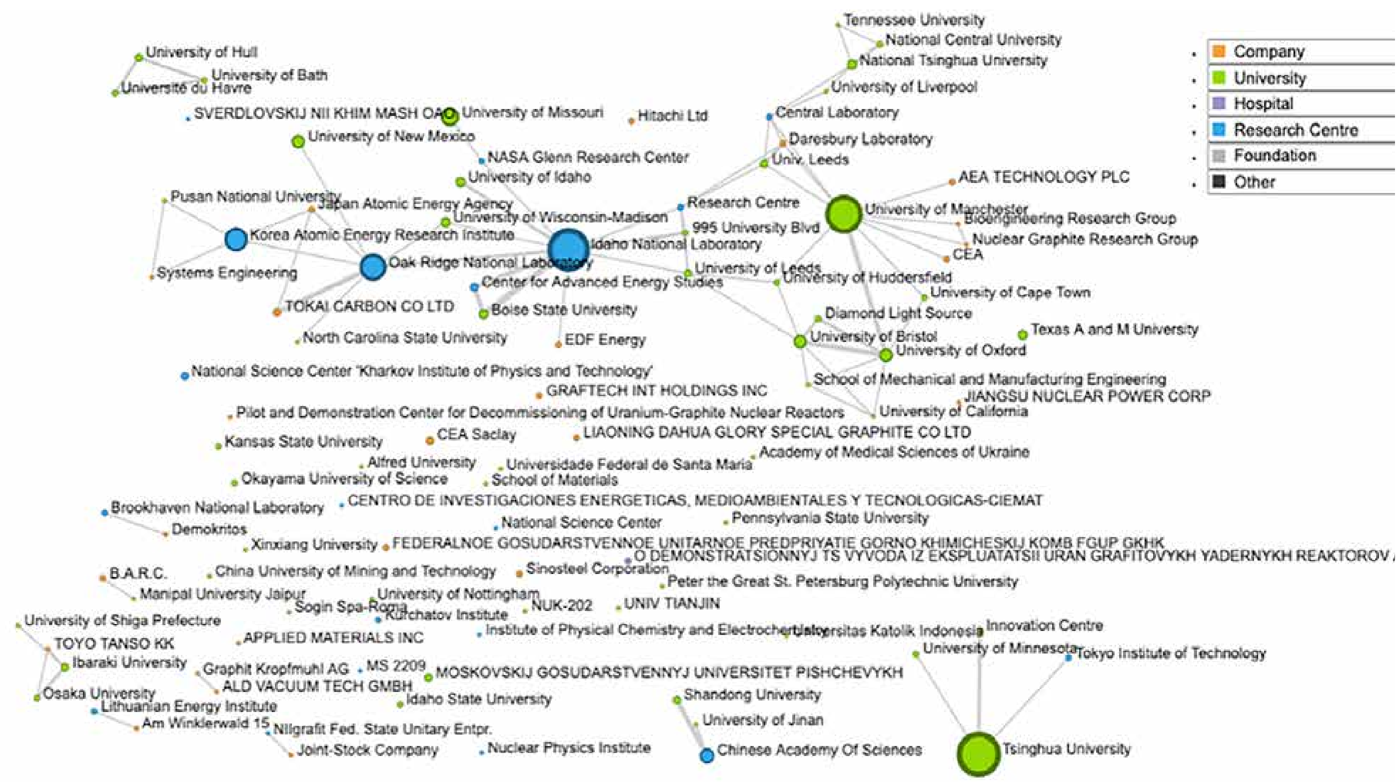

Figure 12: Organisations, shown per type, involved in activities related to (x) Nuclear grade graphite

At the first place is China with 628 documents, half of which are made up of patents. The same proportion applies to the United States, even though Chinese activities are three times more than the ones associated to US organisations. While for Japan, patents account for more than 85% of its 586 activities.

Top 10 involved organisations

Among the top 10 organisations listed by TIM DU, seven of them are companies:

1. Toshiba Corp (Japan);
2. Hitachi Ltd (Japan);
3. Nuclear Power Institute of China (China);
4. Tsinghua University (China);
5. Mitsubishi Group (Japan);
6. CHINA GENERAL NUCLEAR POWER(China);
7. CGN POWER CO., LTD. (China);
8. WESTINGHOUSE ELECT CO LLC (USA);
9. CHINA NUCLEAR POWER ENG CO LTD (China);
10. Korea Atomic Energy Research Institute (Rep. of Korea).

Both Tohiba Corp and Hitachi Ltd realized almost exclusively patents and without any international collaboration. Also the Nuclear Power Institute of China had only domestic collaborations. While the Tsinghua University realized only one international scientific collaboration with the German Karlsruhe Institute of Technology and the American Washington University in Saint Louis. It took place in 2020 and concerned a review of sensors to measure control rod position for nuclear reactor.

The WESTINGHOUSE ELECT CO LLC published a conference proceeding with the Taiwanese National Tsing Hua University on the analysis of PWR reactor vessel upper plenum sections (flow simulation in control rod guide tubes), and a collective conference proceeding with the participation of institutes from Mexico, Japan, Brazil, Italy and Croatia concerning the integral design description of the International Reactor Innovative and Secure (IRIS), including its control rod drive mechanisms.

The Korea Atomic Energy Research Institute contributed to a conference proceeding with several Japanese institutes, including the Japan Atomic Energy Agency, dating back to 2011. The study analysed the fracture behaviour of 2d-c/c composite for application to control rod of very high temperature reactor.

While in 2018, the Korea Atomic Energy Research Institute co-published a study with the Saudi research and governmental entity "King Abdullah City for Atomic and Renewable Energy". The paper studied the applicability of reed switch type rod position indicator for a nuclear reactor.

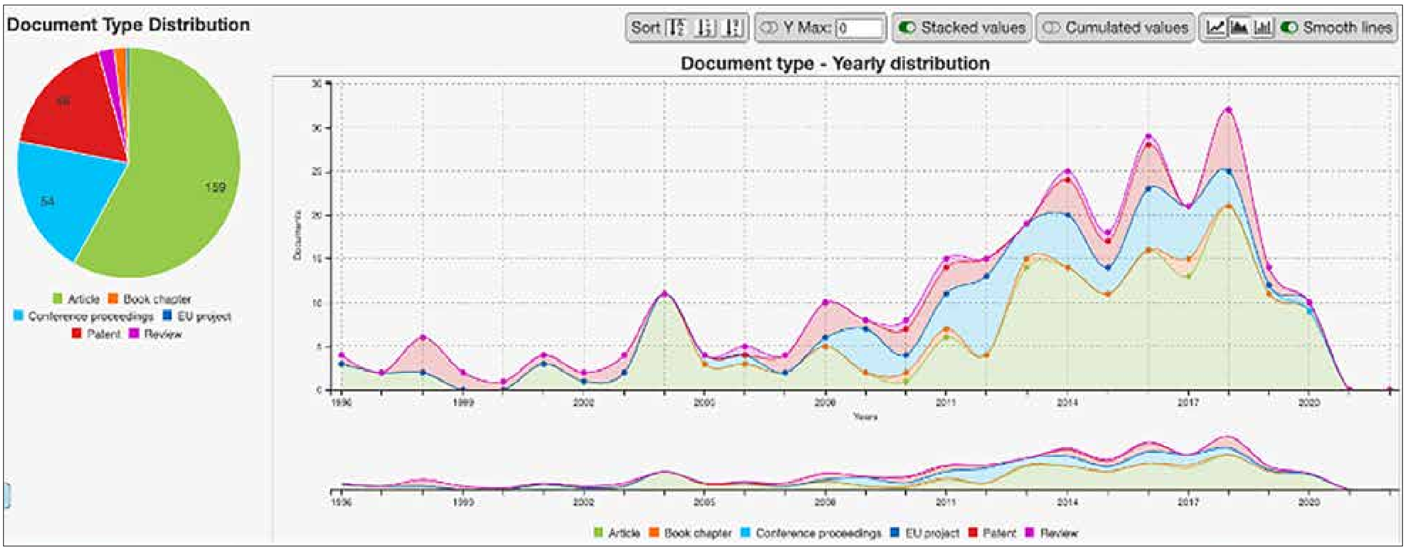

Figure 13: Types of activities related to (xii) Reactor control rods

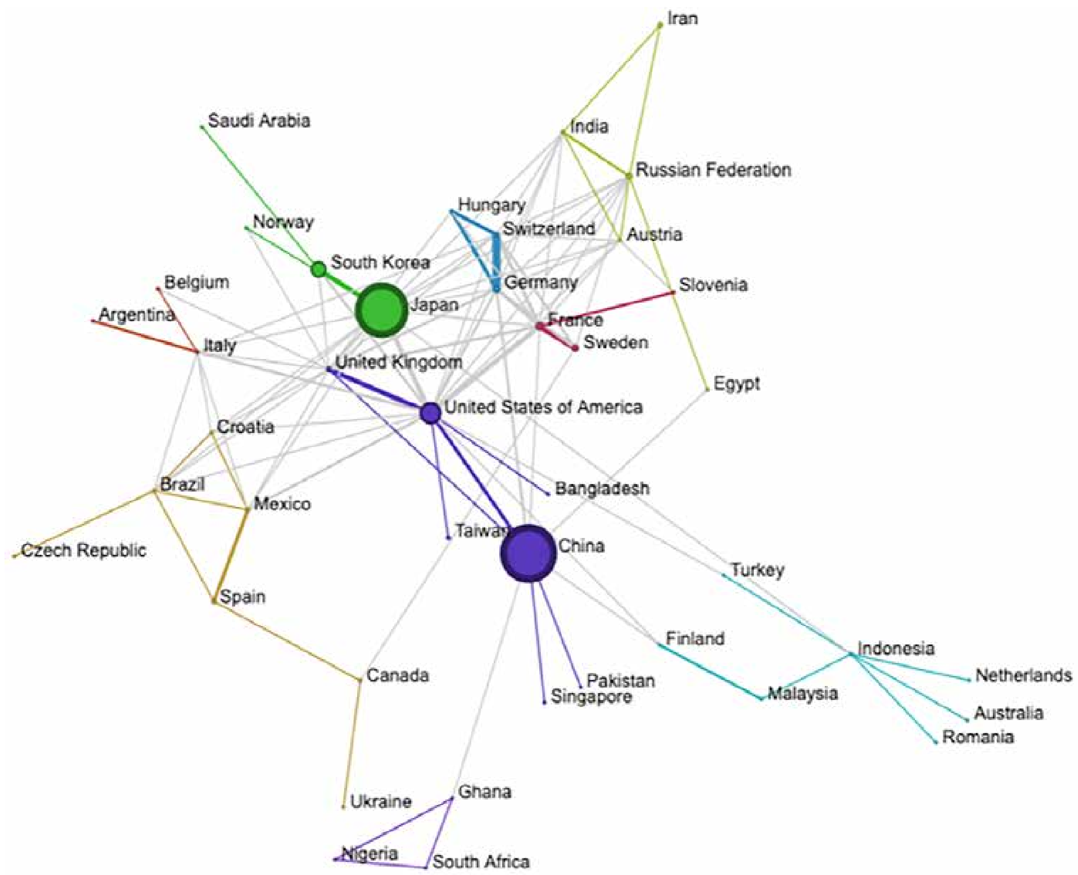

Figure 14: Countries involved in activities related to (xii) Reactor control rods

8. Comments on the TIM DU analyses

The analyses show how TIM DU can provide useful insights both to the national authorities, in charge to provide to the IAEA the information required by the Model Additional Protocol, and to the IAEA to verify the completeness and correctness of the information.

National authorities could get a more complete information about the research carried out in the country about Trigger List related items, including also international research collaborations previously not known and worthwhile to be considered as potential sources of technology transfers.

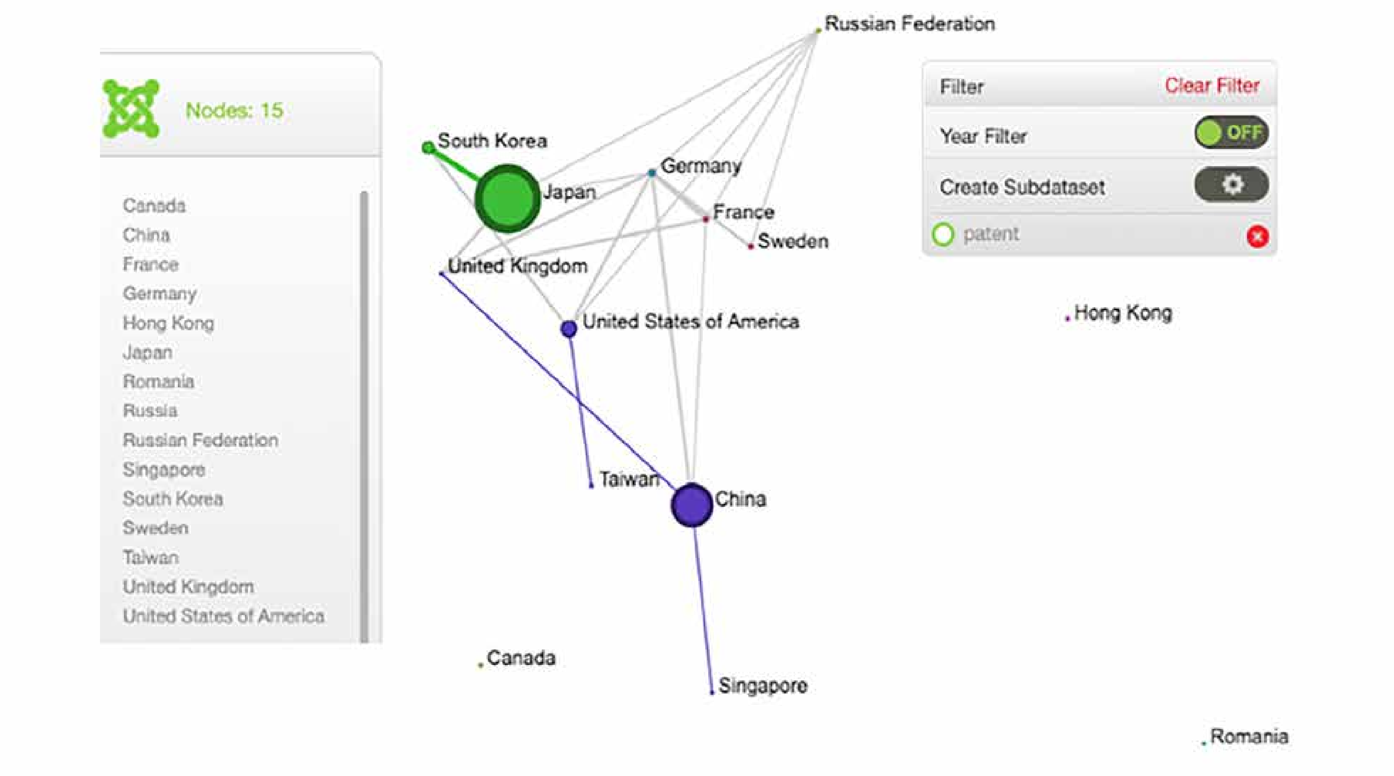

Figure 15: Countries involved in activities related to (xii) Reactor control rods

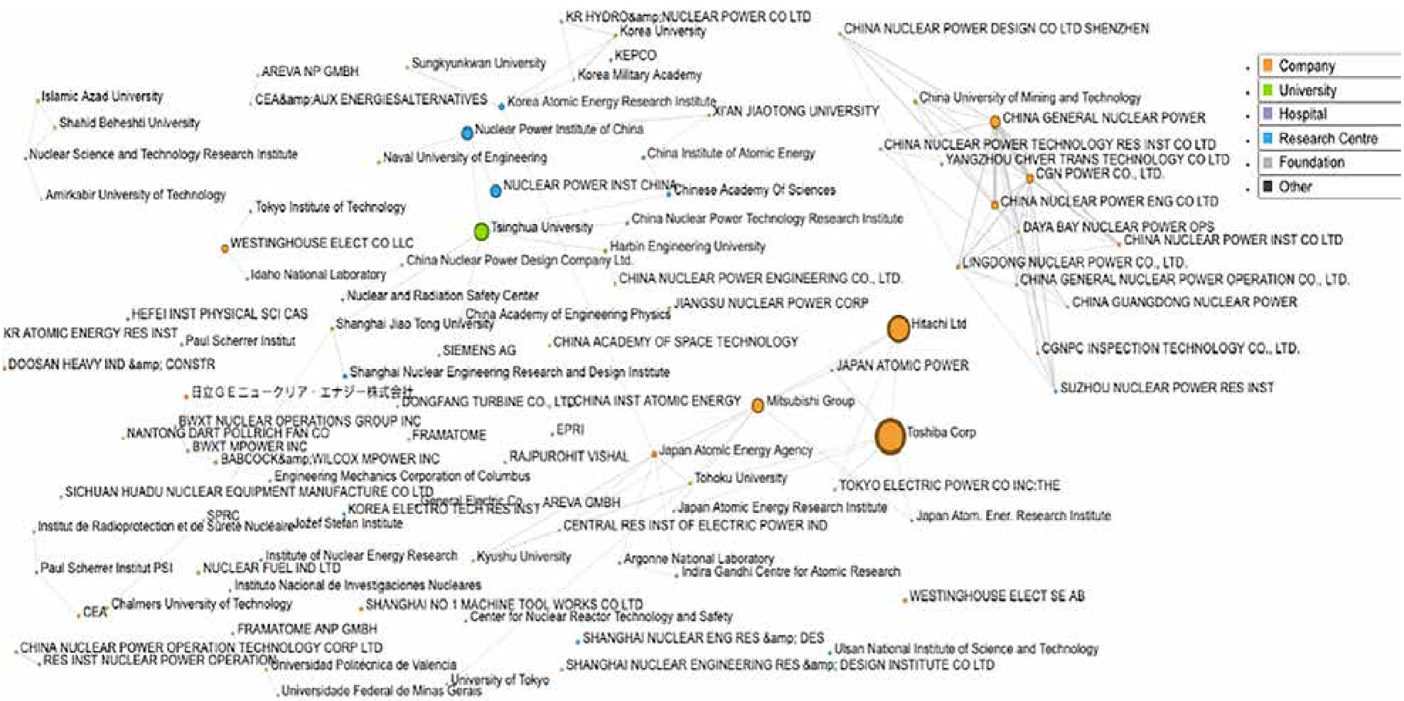

Figure 15: Countries involved in activities related to (xii) Reactor control rods

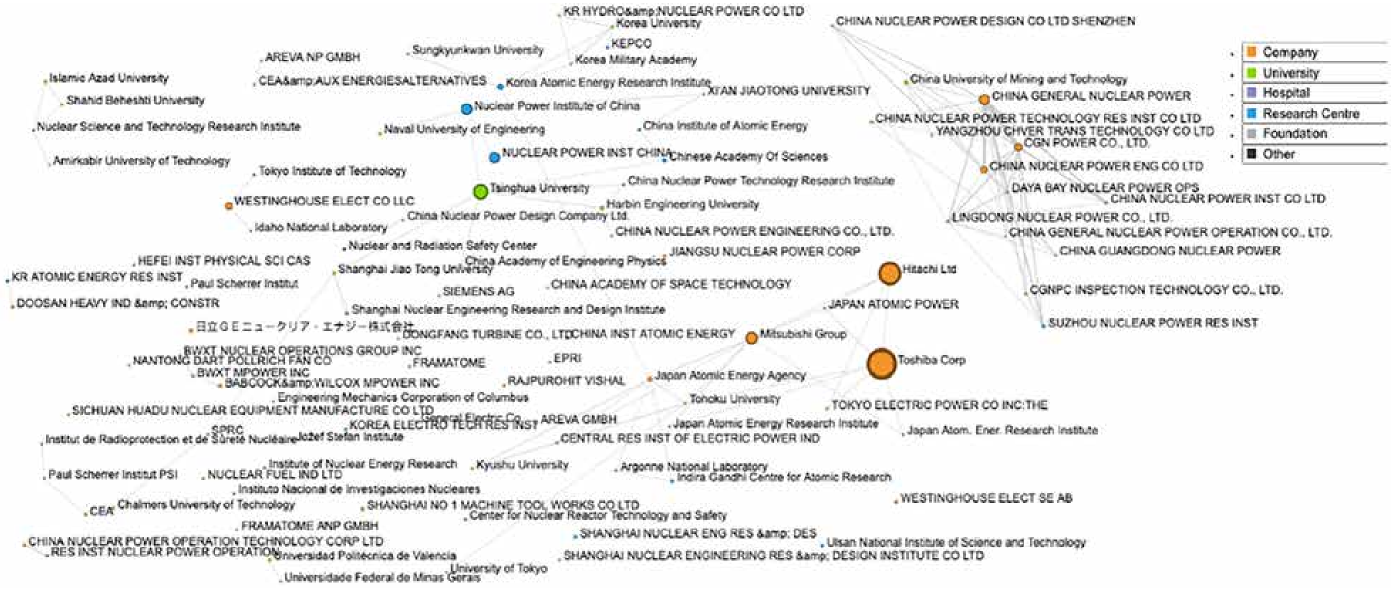

Figure 16: Organisations, shown per type, involved in activities related to (xii) Reactor control rods

For the IAEA, the analyses could be interesting to look at the big picture of indigenous research in connection to international scientific collaborations, possibly involving also technology transfers and technical assistance.

As a starting point, we considered to assess publications and patents related to Annex I's fifteen key nuclear fuel cycle-related activities, because although related to "manufacturing", they have of course also to encompass research activities and the associated technology, i.e. technical data and possibly also technical assistance (art. 2.a.iv).

To be more complete, one could also look at the entire breadth of nuclear research and associated technology by checking with TIM DU the results related to the entire NSG TL, for which queries are also available (Category 0).

By extension, also the verification of the declarations containing export-related information regarding specified equipment and non-nuclear material listed in Annex II (art. 2.a.ix) could be complemented by assessing possible nuclear technology transfers by TIM DU datasets covering both the NSG lists, noting also that the minimum technology for installation and maintenance is automatically included in the export authorisation of tangible goods.

Along this line, we would add as a final observation that, although not called for by the AP, we consider essential to verification also checking the items listed in the Nuclear Suppliers Group Dual-Use List, including goods, software and technology. As shown by the most notorious proliferation cases, dual-use items are indeed integral, and sometimes alternative, key elements for undeclared illicit manufacturing activities, that could involve also research and intangible technology transfers.

TIM DU is also a valuable export compliance support to researchers, called to comply with export regulations. By detecting past scientific production potentially involving dual-use items, TIM DU could be a valuable help for better targeting specific research entities to raise their awareness and encourage them to tailor their internal compliance programmes .

An in depth assessment of the material obtained (full paper of the abstracts, public patents) is anyway needed, also before concluding that the documents might have required export authorisations. TIM DU's datasets include the list of abstracts retrieved by the query, with hyperlinks to the original journal, where the full article may be available or purchased. For patents, the hyperlink leads to the information contained in PATSTAT; the same happens for an EU-funded project stored in the CORDIS database.

A disclaiming note is also necessary: TIM DU's queries allow retrieving documents possibly related to dual-use controlled items, but a certain degree of uncertainty is inherently present. The collections of datasets retrieved may not be complete, nor always fully relevant to the object of the query. As previously outlined, at times, there might be errors deriving from incorrect downloading of the database records. Depending on the original information provided to the journals and then sent to SCOPUS, organisations' names might differ for the use of full titles, acronyms etc. Part of the analysis is dedicated to cleaning the data accordingly.

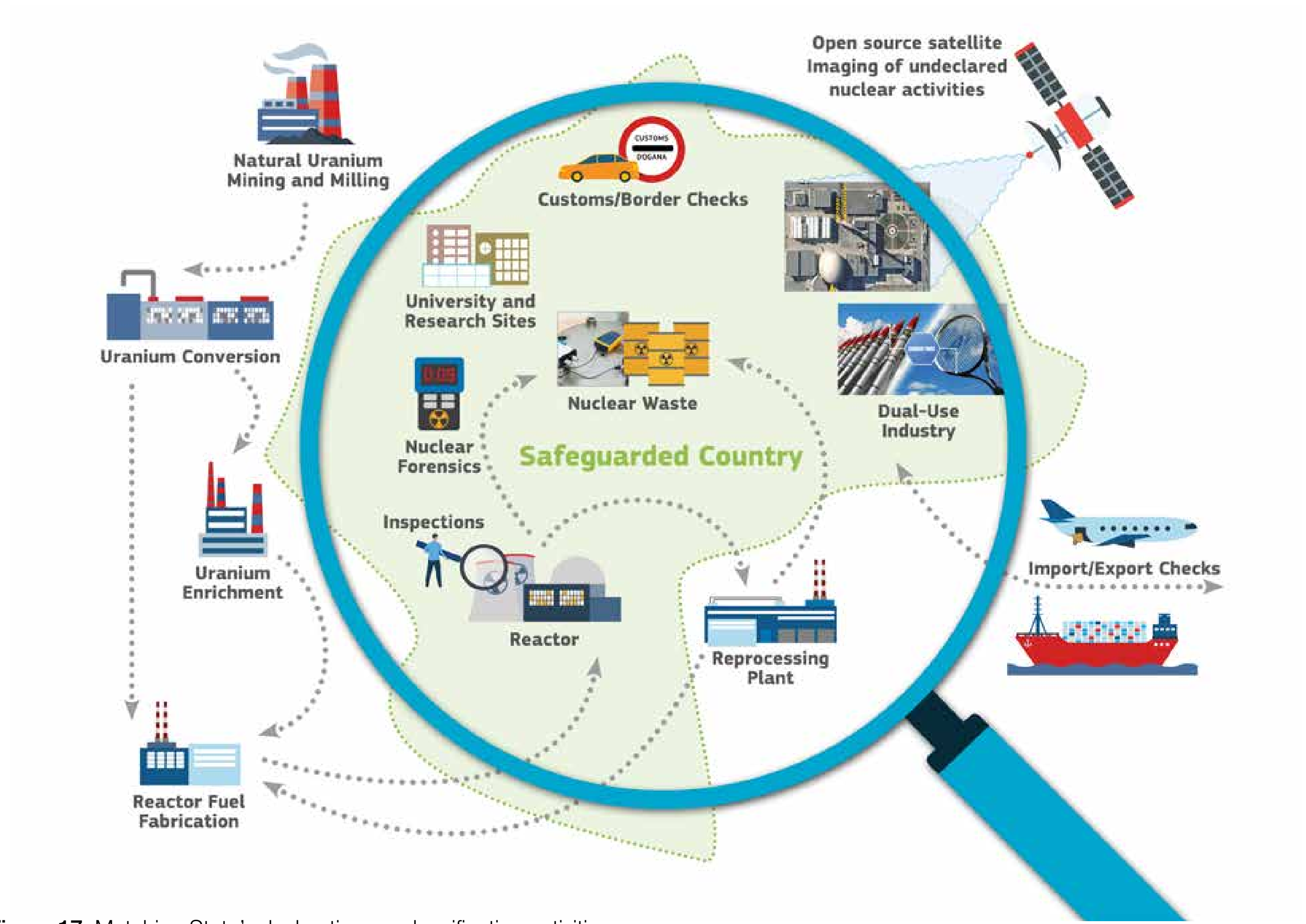

Figure 17: Matching State's declarations and verification activities.

9. Conclusions

Strategic export controls are a barrier against proliferation and the unauthorised access to strategic technology and goods, which developed in parallel to nuclear safeguards for decades.

The verification of the completeness and correctness of the declarations to the IAEA is an important element of the analyses and inspection activities leading to the conclusion about the absence of undeclared activities, as summarised in Figure 17.

Besides manufacturing activities and exports of tangible items, also research activities and transfers of nuclear technology may play an important role in proliferation programmes.

Various types of information are required by the Model Additional Protocol, including nuclear research in areas pertaining to the nuclear fuel cycle, also not involving nuclear materials.

Together with many dual-use goods and emerging technologies, TIM DU maps nuclear-fuel cycle activities' scientific abstracts, patents, and EU-funded projects, allowing to gather lists of documents, geographical distributions, collaborations, and authors, providing a quantitative and qualitative overview of the potential issues and to identify areas of possible risk.

These results can be helpful to the national authorities submitting declarations to IAEA in accordance to Additional Protocol's Article 2.a, both to identify previously unknown national research actors and to raise the awareness of national research entities about potential sensitivities with external collaborators.

The IAEA could also use TIM DU to support the verification of the completeness and correctness of declaration concerning research about the nuclear fuel cycle.

Research organisations and other involved entities could also consult TIM DU to identify their past scientific production, which could include dual-use aspects and tailor their compliance programmes accordingly.

TIM DU has been launched in January 2021 and is under continuous testing and validation. Any useful feed-back will be precious and enabling our future improvements. While the nuclear controls are extensively mapped, more queries may be necessary to complete the other dual-use categories.

10. Acknowledgements

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