Summary Report

International FEL Expert Meeting

Use of free-electron lasers and beyond: Scientific, technological, and legal aspects of dual use in international scientific cooperation

4–5 November 2019 at DESY Hamburg, Germany

Editors:

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Preface

BY HELMUT DOSCH AND ROBERT FEIDENHANS'L

Rapid progress of modern X-ray sources, such as free-electron-lasers (FELs), offers new scientific opportunities while continuously pushing technological boundaries. We at DESY and European XFEL are operating complex and highly advanced large-scale research infrastructures for international user communities in open access, allowing research by our statutes for civil purposes only. In this respect, we are deeply committed to handling research at our facilities in a most responsible way and abiding by the regulatory frameworks of export control. A highly relevant area for responsible acting is related to so-called "dual use" technologies that could have both civil and military applications. It is important to identify, from early on, sensitive issues and areas of dual use, while minimizing the involved threats and misuse. However, scientific applications and technologies, in particular at FELs, are advancing, and we are entering new terrain that requires serious assessments about to which extent dual-use research might become an issue. Such concerns and considerations have to be taken seriously at laboratories and in the international research communities—otherwise, we risk losing the benefits of an open science system with international collaboration coming under intensive pressure and restrictions.

This motivated us to organize an international expert meeting where FEL science and technologies were discussed in relation to potential military applications. The meeting was held on 4–5 November 2019 in Hamburg, and was, in our view, a big success. It was a major feature to bring together expert scientists from various fields and senior officials from major accelerator labs all over the world to exchange and share our experiences and assessments on sensitive issues around FELs and related technologies. Guidelines and policies facing the challenges of handling responsible research were discussed, as our organizations must also have proper practices in place in order to ensure full compliance under national or European regulation frameworks, such as export control.

The expert meeting was both stimulating and informative, with a wonderful array of international keynote speakers and discussants. For the meeting, open communication was strongly encouraged and constructive; trust-building and forward-looking dialogue among the international attendees took place. Here, it was of utmost importance for the discussions to have the participation of our Chinese, Japanese, Russian and US, colleagues to understand their respective views on these subjects.

The rich programme provided all attendees with the opportunity to meet and interact with one another. We believe that the experience of the participants at the expert meeting in

November was a fruitful experience and will bear a long-lasting and fond memory for our guests.

We are now very pleased to present you with this report as a summary of the international expert meeting. All keynotes and main contributions from the parallel sessions as well as the session summaries are captured and documented in this report. In the subsequent discussions, when writing this report, additional issues could be better clarified and further information that came to light was included. All of this helps us to raise the appropriate awareness and to sharpen the understanding of dual-use issues within the community. The report also offers some findings that we hope will impact future discussions and policies to better manage and handle research.

We would like to warmly thank the editors, W. Kircheisen, F. Lehner, F. Le Pimpec, and G. Neuneck, as well as the contributing authors and all reviewers. They have worked very hard in generating this document and in making very valuable suggestions to improve the work.

With all your support and active engagement for this report, we hope that the expert meeting and its results will have a long-lasting positive impact on international collaborations.

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Figure 1: Participants of the expert meeting posing at the FLASH conference room

Introduction to the FEL dual-use expert meeting

Free-electron lasers (FELs) and related technology developments have opened up a new range of unique scientific opportunities to achieve significant advances in physics, chemistry, materials, and the life sciences that will rapidly extend the boundaries of our knowledge. As shown in more detail in the next section, FELs have unprecedented capabilities and provide the most brilliant, coherent, and ultrashort pulses to address key scientific questions in a way no other type of facility or technology can presently match. Advances in FEL-related science and technology developments are pursued globally in Europe, the USA, and Asia. Many scientific actors—among them DESY and the European XFEL as leading institutions—have close international collaborations and see open international exchange as extremely valuable and beneficial to the community.

Hand in hand with the fast progress and the broad scientific benefits, handling forefront research and development in a responsible way also remains a key mandate for the involved scientific communities and research organizations. Pushing the frontiers combined with new technologies leads to growing questions and concerns about if and how civil and military applications can be properly distinguished in an international open-science environment and to what extent and depth aspects of potential dual-use applications have to be seriously considered and controlled.

All stakeholders involved must therefore take individual responsibility to assess the potential nature, seriousness, and consequences of possible dual use or misuse related to the intended knowledge, technologies, and their applications. Principles and policies in science communities and in international cooperation must be defined to mitigate any dual-use risks and minimize any misuse while still maintaining and safeguarding open international collaboration around FELs as much as possible.

With this concern in mind and driven by the fact that both DESY and European XFEL have in their founding charter or convention, respectively, the duty to conduct civil and peaceful research only [1, 2], DESY and European XFEL organized an international expert meeting in November 2019. It was aimed at identifying and assessing the potential risks of dual use in the fields of FEL science and technology and at devising a nuanced approach based on best practices to guide the international research community. Approaches were taken to consider the topic from various angles, including scientific, technological, and legislative aspects.

The concrete objectives of the expert meeting were formulated as follows:

- Identify and assess potential dual-use issues in FEL-related science and technology (S&T) areas—organized in four S&T sessions.
- Discuss and exchange best practices on dual-use aspects, awareness, control, and policies.

- Explore best principles and practices to minimize dual-use risks and proliferation concerns in international collaboration.

- Contribute to an international and forward-looking dialogue for scientific collaboration in times of global tension.

The overall goal of the meeting was to devise a set of guidelines/directions for how to deal with sensitive issues in international collaboration. The expert meeting was scheduled over 1.5 days with plenary and parallel sessions. At the end of each day there was an open plenary forum that reported back from the parallel sessions, enabling everybody to speak up and facilitating open discussions as well as wrapping up and concluding the session. While Day 1 of the meeting was devoted to setting the scene and to the scientific and technical assessment of dual-use issues, Day 2 aimed at applying the findings to transfer them into principles, guidelines, and policies.

On Day 1, some speakers were asked to give their views and experiences on the balance of science and national security in the plenary session to better understand the context of the exercise. After the first talk on the lessons learned from history to balance national security and open scientific collaboration, representatives from the US, Russia, China, and the European Union (EU) elaborated their international perspectives. The presentation on the issue of dual-use and export-control systems emphasized the motto "clarity drives compliance". Collaborating with international partners is only possible if one builds trust—without forgetting that exercising layered security is inherent to it. From the understanding of what an X-ray FEL is and from the various historical and experience-based views presented, technical topics could be tackled.

The technical topics of Day 1 were organized in parallel working groups:

- FELs and energy-directed weapons
- Superconducting (SRF) accelerator and photon system technologies
- FELs and isotope separation
- FEL science: Materials under extreme conditions and other science

The meeting was designed as an international forum for renowned experts and senior officials from various countries for informal discussions and for best-practice exchange supporting the use of scientific and evidence-based findings. One of the major goals of the meeting was to bring together key international experts from different regions to promote trust-building in an international, open, cooperative, and forward-looking dialogue, in a world that sees more and more tension and emerging military competition around new technologies. The meeting benefitted strongly from the openness of the discussions and from the trust-building dialogue. Everyone was encouraged to speak as an individual and to express their views openly and honestly, including opinions not necessarily derived from their organizations or governments. Hence, the overall rule of the workshop and sharing of the information followed the Chatham House rule [3, 4]: "Participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed.” At the same time, this report does contain summaries contributed voluntarily by speakers who allowed us to reveal their names, and it provides a list of participants who have similarly allowed their names to be presented (see the “List of participants” section on p. 65). There are also additional summaries provided by a subgroup of the participants from the break-out sessions that provide content and context of these open yet focused discussions. Those summaries are complemented by references on the subject and an extended bibliography on the topic of dual use in S&T and on governance is provided in a specific “Extended bibliography” section.

References

[1] DESY mission and guiding principles
http://www.desy.de/about_desy/mission_and_guiding_principles/index_eng.html

[2] Convention concerning the construction and operation of a European X-Ray Free-Electron Laser Facility (incl. Articles of Association and Final Act, Article 1)
https://www.xfel.eu/organization/company/index_eng.html

[3] https://www.chathamhouse.org/chatham-house-rule

[4] https://en.wikipedia.org/wiki/Chatham_House_Rule

Principles of FEL science and technology

Introduction to FELs: Setting the scene

In order to understand the potential issue with free-electron lasers (FELs), especially related to X-ray FELs in the context of dual-use, it is important to understand the capacity of those state-of-the-art types of accelerators and the technologies associated to them. We of course focus on superconducting FELs, like the European XFEL and FLASH at DESY, because of the potential to achieve high peak power and to open up new fields of sciences dealing with very fast (femtoseconds range) processes.

The European XFEL is located in the greater Hamburg area in northern Germany. It is a linear accelerator based on superconducting radio frequency (SRF) technology, capable of accelerating electrons close to the speed of light to energies up to 17.5 GeV. The European XFEL provides very short and intense flashes of X-ray light and, like all FELs, its photon beam peak brilliance is orders of magnitude above the state-of-the-art synchrotron radiation light sources (SRS).

The core of the accelerator, to provide the intense X-ray light, is made up of two main components:

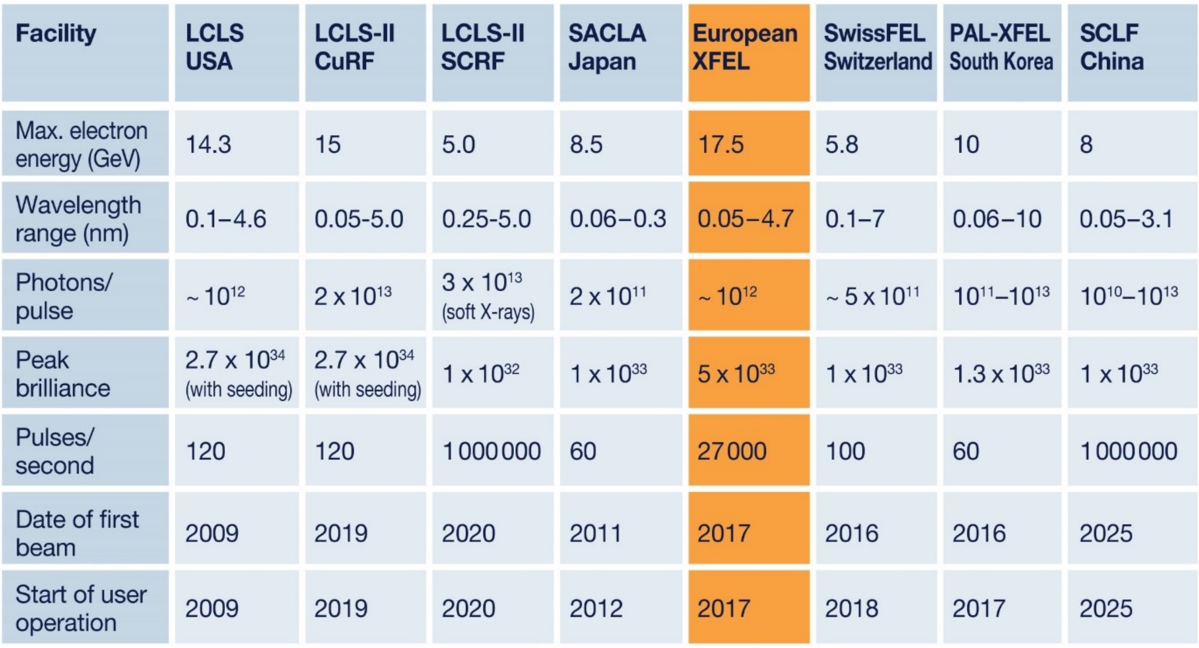
- A 1.2-km-long linear accelerator based on superconducting Niobium accelerating structures cooled at temperature of 1.9 K (~2 degrees above the absolute zero).
- A set of permanent magnets, called undulators, which are up to 150 m long and are capable of wiggling the electrons in the horizontal plane, emit a broad spectrum of light at each change of direction of the electrons and—with the appropriate relation of phase between the undulator period, the magnetic field in the undulator and the electron bunch properties—provide, at a given wavelength, a light that is laser-like, meaning that it is mostly coherent transversely and also to some extent in time.

Because FEL light is so intense, anything that crosses it for a few seconds may be destroyed or at least seriously damaged. This capability raised interest in the early 1980s as a possible anti-ballistic missile defence technology. Thanks to such a short and intense flash of light, another interest has been the possibility to probe the state of matter prepared by other means (diamond anvil cell or by dynamically compressing using optical long laser pulse) that may be encountered in the core of giant gas planets, like Jupiter, as well as to study ultrafast phenomena in the life sciences, material research, and other fields touching the picosecond level and faster in the future.

That said, it is important to review the operation and technologies associated with a FEL as well as to have an overview of existing X-ray FELs around the world.

Starting from the second point, as of today, six X-ray FELs are in operation around the world. The two in Hamburg are based on superconducting RF technology and are complementary in terms of the X-rays they can deliver for science. The other four are based on normal conducting RF (copper-made accelerating structure cooled by water at usually ~30C). The first operating X-ray FEL (LCLS) is located at SLAC in California (USA), the second in Japan near Osaka (SACLA), the third in South Korea near Pohang (PAL-XFEL), and the fourth in Switzerland near Zurich (SwissFEL). Because of the ever-growing need for such machines and the desire to achieve superior performances, LCLS is upgrading to a SRF-type machine (LCLS-II) and China is building an SRF machine based on publicly available technology predating 2005, with a new design as well as a different mode of operation from the European XFEL or FLASH. We will not say much about the SRF technology in this section, as a special session was dedicated to it and is summarized later in the report.

Figure 2: Comparison of the hard X-ray FEL Figure 2 presents the various capabilities of the different major X-ray FEL projects.



Facility	**LCLS USA**	**LCLS-II CuRF**	**LCLS-II SCRF**	**SACLA Japan**	**European XFEL**	**SwissFEL Switzerland**	**PAL-XFEL South Korea**	**SCLF China**
Max. electron energy (GeV)	14.3	15	5.0	8.5	17.5	5.8	10	8
Wavelength range (nm)	0.1–4.6	0.05-5.0	0.25-5.0	0.06–0.3	0.05–4.7	0.1–7	0.06–10	0.05–3.1
Photons/ pulse	~ 10^{12}	2 x 10^{13}	3 x 10^{13} (soft X-rays)	2 x 10^{11}	~ 10^{12}	~ 5 x 10^{11}	10^{11}–10^{13}	10^{10}–10^{13}
Peak brilliance	2.7 x 10^{34} (with seeding)	2.7 x 10^{34} (with seeding)	1 x 10^{32}	1 x 10^{33}	5 x 10^{33}	1 x 10^{33}	1.3 x 10^{33}	1 x 10^{33}
Pulses/ second	120	120	1 000 000	60	27 000	100	60	1 000 000
Date of first beam	2009	2019	2020	2011	2017	2016	2016	2025
Start of user operation	2009	2019	2020	2012	2017	2018	2017	2025

Figure 2: Comparison of the hard X-ray FEL projects (note that SCLF is now called SHINE)

In order to operate such machines—which are presently at least 600 m in length to reach a wavelength of 0.1 nm—special diagnostics, electronics, advanced control systems, sample delivery systems, X-ray detectors, and X-ray optics must be developed. These technologies are sometimes easily available on the market; but, for some technologies, only a handful or even a sole private provider worldwide can comply with the requested specifications; and, in some cases, the technology must be developed in house with much significant collaboration with other laboratories already hosting such an X-ray FEL. This third case is especially true for X-ray detectors capable of dealing with the pulse mode of the European XFEL and, in the future, with the high repetition rate of the "continuous wave machines" (CWs) of accelerators such as LCLS-II in the USA (near San Francisco) or SHINE (formerly SCLF, in Shanghai) in China (see *Figure 2: Comparison of the hard X-ray FEL* Figure 2).

In conclusion, today’s X-ray FELs are not usable for direct military applications because of the difficulty of building and operating such machines. It is important to stress that it takes decades to produce a working prototype, and the resources and materials to conceptualize, design, and build them very often come from a variety of contributions from various collaborators and institutions around the globe. However, the science and objectives addressed by such major projects may be interesting for some military applications (e.g. studying the state of matter not present under normal conditions on Earth or probing the properties of high-Z materials). The European XFEL precludes work on military applications through its intergovernmental convention linking the 12 shareholders of the company, which requires the facility to “undertake activities for peaceful uses only”. It is up to the management of European XFEL to elaborate guidelines and then convey these legally bound guidelines to the users, and implement procedures to ensure that they are followed, to strengthen the international nature of X-ray FEL science.

References

[1] “Convention concerning the construction and operation of a European X-Ray Free-Electron Laser Facility” (incl. Articles of Association and Final Act), https://www.xfel.eu/organization/company

Balancing open-science collaboration and national security: Lessons learned from history and current challenges

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Since the era of enlightenment, science is rooted in the idea of humanism and progress. Over centuries, science has been developed as a powerful tool to understand the world and to ease the burden on humankind and in daily life. Its main principles are objectivity, neutrality, international exchange, and rational reasoning. Scientific work is based on experiments, empirical testing, analysis, modelling, verification/falsification, and open exchange by sharing data and techniques through publications and collaborative projects. These conditions for science are endangered by distorting facts for nationalistic purposes and by new military or terror applications causing damage. From a geopolitical perspective, the "return of great-power competition" announced by the Trump administration will affect science and technology (S&T) in general and directly (international exchange and cooperation, programmes, etc.). A new scientific–technological arms race in specific fields could become not only costly but dangerous by suppressing joint collaboration and academic exchange. Open science is challenged by all these developments [1].

Over the centuries, the results of scientific work were also used or misused for warfighting, terror attacks, and other destructive purposes. In World War I (WWI), basic chemistry was elaborated to produce chemical weapons. Building nuclear weapons at the end of World War II (WWII) was possible only by basic and applied research, development, and testing. During the Cold War, massive programmes with thousands of scientists and engineers created very large arsenals of many types of nuclear, chemical, and biological weapons, including a spectrum of delivery systems that made the extinction of mankind in 24 hours possible. In his farewell speech in 1961, U.S. President Dwight D. Eisenhower warned "against the acquisition of unwarranted influence […] by the military-industrial complex" [2]. He also stated that, in the ongoing technological revolution, "research has become central". Beyond physics, chemistry and the engineering developments in life sciences, new scientific fields such as informatics, materials, and space technology helped to create new military applications for military arsenals and for warfighting. S&T fields—like artificial intelligence and autonomous systems, space-based technologies, etc.—are emerging and have a high potential of creating new technologies that can likely be of a dual-use importance [3]. The proliferation of militarily relevant technology, knowledge, and materials in a globalized world is ongoing and, due to the Internet, the leakage of sensitive information is more likely than ever. The often-stated great-power competition between the USA, Russia, and China, as well as the industrial competition between rising economic powers and blocs, seems to accelerate the danger of new technological arms races.

During the Cold War, scientists not only had the role of creating new results in laboratories (Edward Teller, Andrei Sakharov) but also worked as advisors (John von Neumann), strategists (Hermann Kahn), programme managers (Wernher von Braun), etc. Sidney Drell wrote in 2000 that "history teaches us that new technologies have had a major influence on the structure, tactics, and strategies of military forces, and that technological advantage can prove decisive to the outcome of military conflicts" [4]. Balancing open science with national security needs was and still is very often a controversial theme in societies (nuclear deterrence, artificial intelligence, etc.) as well as within the scientific community (e.g. Strategic Defense Initiative (SDI)). Science sometimes benefitted from high financial contributions, but the science community was also critical of security-related defence programmes that could fuel arms races or new offensive options.

Shortly after the Hiroshima and Nagasaki nuclear bombings in 1945, scientists also worked to prevent a planetary disaster by studying the consequences of war (e.g. radioactive fallout, nuclear winter), developing verification tools, technologies, and protocols for arms control and disarmament treaties or establishing international organizations, such as the International Atomic Energy Agency (IAEA) or the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO). Additionally, arms control treaties ("*ius contra bellum*") such as the Anti-Ballistic Missile (ABM) Treaty or the Biological and Chemical Weapons Conventions (BWC and CWC) were proposed and developed to prohibit the possession, acquisition, or use of weapons of mass destruction (WMD). Based on the Geneva Conventions, the "International Humanitarian Law" (IHL) created principles and protocols to restrict the use of certain conventional weapons that are considered excessively injurious and inhumane or whose effects are indiscriminate ("*ius in bello*") [5]. Today, the scientific community is dedicated to improving scientific results, but often ignores the adverse influence of the scientific reasoning on humankind, public health, and the environment in military competition.

Also during the Cold War, the Pugwash Conferences on Science and World Affairs [6] created a series of workshops for "Track II diplomacy" to bring together non-governmental scientists, decision makers, and experts for conflict resolution in fields where the use of WMD was apparent [7]. International scientific projects—such as SESAME [8], the International Space Station, or LIGO—also do much for "working across the borders", helping to connect people in today´s fractured world. International projects led by international or national institutions such as CERN or DESY are other bright examples of peace-, bridge-, and confidence-building within the scientific community. Beyond arms control and disarmament, proliferation prevention and risk reduction represent yet another strand of mitigating the risks of destabilizing or harmful consequences of scientific work. Arms trade controls are also important on the governmental level, while raising public awareness is important on an individual level.

There are several established methods and tools to prevent the harmful application of scientific results:

- Building public and community awareness for dual-use applications to mitigate risks in the scientific community

- Understanding and applying arms export control regulations to prevent the transfer and misuse of dangerous goods
- Applying norms and principles of arms control and humanitarian law to S&T
- Strengthening the social responsibility of scientists and engineers through awareness including though the discussion and analysis of ethical and historical cases and dilemmas

Science needs freedom and international exchange, but this freedom also entails *responsibility*. The scientific community as a whole—as well as independent individuals and research institutions—bears a special responsibility to help societies better understand the implications of dual-use developments and to restrict dangerous risks to human dignity, life, health, freedom, property, and the environment. Very often, the results of research cannot be predicted directly because future-use applications and second- or third-order effects are often unknown. Raising awareness for legal provisions—such as prohibiting research objectives in the nuclear, biological, and chemical (NBC) area that violate international treaties and norms or national regulations—and regulating methods or banning exports and knowledge transfers to specific countries should be key in enlightened countries. Other ways forward are undertaking “risk analyses”, minimizing risks by evaluating high-risk research before it starts. Foregoing research is a last resort. Education of younger scientists is another way forward as well as participating in public debates to inform interested stakeholders about future possible consequences. Research institutions can also develop or adapt existing ethics rules for handling security-relevant research that goes beyond legal compliance in a transparent way.

Arms export control is a denial strategy that establishes a network of national regulations prohibiting the transfer of certain commodities or information, motivated by national or international security concerns or economic trade interests. In Germany, this aims at handling critical goods, including technology, software, and sensitive knowledge transfer as an important element of its non-proliferation strategy [9]. Because science can create new technologies and knowledge and because technologies that were previously of concern may have diffused internationally to the point that controls are infeasible, an update to the list of critical goods and transfers is necessary. Scientists must become more familiar with state-established regulations in a globalized world, and arms export agencies should maintain regular contact with research institutions. In addition, the harmonization of national standards in entities such as the European Union (EU) is a challenging task.

A wide spectrum of arms control and disarmament treaties as well as techniques and procedures for the verification of compliance were developed during and at the end of the Cold War. The Biological and Chemical Weapons Conventions do not restrict research but prohibit the development, testing, production, acquisition, and use of biological and chemical weapons. More treaties in the nuclear military field created geographical restrictions (nuclear weapon-free zones), non-proliferation norms (Non-Proliferation Treaty, 1970), or the prohibition of nuclear testing to block vertical proliferation (Comprehensive

Nuclear Test Ban Treaty, CTBT). Arms control can be defined as a process to achieve security no longer through unilateral defence and armaments policy but through cooperative influence on mutual armaments behaviour. The specific functions, instruments, and manifestations of arms control change according to the stage of the conflict relationship between the opponents/partners. Major arms control treaties (e.g. New START [10]) are eroding due to a lack of interest, expertise and the one-sided interest of nationally focused policy. There is an acute danger that past arms control efforts will give way to accelerating new arms races. Fixed principles—such as weapons limits, war prevention, parity, transparency, risk reduction, and verification—are being challenged by new actors and competitors [11].

Additionally, a new wave of emerging and advanced technologies in the field of cyber warfare, outer space, biology, chemistry, and physics could have a major impact on international security. Applications of artificial intelligence, nanotechnology, quantum technology, and robotics may create new kinds of weapon applications triggering disruptive or destabilizing elements in war-like situations or even changing military balances.

Science organizations have worked to strengthen the social responsibility of scientists. UNESCO elaborated in 1974–2017 recommendations on science and scientific researchers [12]. The German National Academy “Leopoldina” published in 2014 a *Handbook for Handling Security-Relevant Research* on the individual and institutional level [13]. Other national societies, such as the Royal Society or the US National Academy of Sciences, have held discussions and written reports on legal obligations or conducted risk analyses in militarily relevant fields. The biggest deficit here is that some researchers are neither prepared nor willing to invest extra time to participate in analysis or discussions. Raising public awareness and citing historical cases or dilemmas can help here to prevent the misuse of research findings.

References

[1] “Military Work threatens Science”, Nature **556**, 273 (2018)
doi:10.1038/d41586-018-04588-1

[2] Dwight David Eisenhower: “Farewell Address: On the military-industrial complex and the government-universities collusion”, 17 January 1961
http://www.panarchy.org/eisenhower/farewelladdress.html

[3] Current Developments in Science and Technology and their Potential Impact on International Security and Disarmament Efforts. Report of the Secretary-General Report of the UN Secretary-General, General Assembly A/73/177, 17. July 2018,
https://undocs.org/a/73/177

[4] Sidney D. Drell: “On Physics and National Security”, Physics Today, **53** (12), 25–29 (2000)
doi:10.1063/1.1341911

[5] See the 1983 Convention on Certain Conventional Weapons https://www.unog.ch/80256EE600585943/(httpPages)/4F0DEF093B4860B4C1257180004B1B30

[6] Pugwash Conferences on Science and World Affairs
https://pugwash.org/

[7] See for example: Andrew Brown: *Keeper of the Nuclear Conscience. The Life and Work of Joseph Rotblat*, Oxford 2012

[8] Synchrotron-Light for Experimental Science and Applications in the Middle East (SESAME) https://www.sesame.org.jo/

[9] Guidelines and a manual are available for the industrial and scientific sectors https://www.bafa.de/DE/Aussenwirtschaft/Ausfuhrkontrolle/Academia/

[10] New Strategic Arms Reduction Treaty (New START)
https://www.state.gov/new-start/

[11] Götz Neuneck: "The Deep Crisis of Nuclear Arms Control and Disarmament: The State of Play and the Challenges", Journal for Peace and Nuclear Disarmament **2** (2), 431–452 (2009) doi:10.1080/25751654.2019.1701796

[12] "Recommendation on Science and Scientific Researchers", UNESCO General Conference 2017, ANNEX II and Consolidated report on the implementation by Member States of the 1974 Recommendation on the Status of Scientific Researchers https://unesdoc.unesco.org/ark:/48223/pf0000259256

[13] Leopoldina/Deutsche Forschungsgemeinschaft: "Scientific Freedom and Scientific Responsibility: Recommendations for Handling Security-Relevant Research on the Individual and Institutional Level" (2014)

International perspectives: Summaries of the talks from the USA, Russia, China, and Europe

This section, compiled by the editors based on the presentations delivered during the plenary session, explores how international scientific collaboration and dual-use issues are addressed in the usually economically competing but also scientifically collaborating countries and regions of the USA, Russia, China, and Europe. It also describes how the political change and regulations that cope with technological development introduced in the previous discussion affect our established or future scientific interaction.

A US view of dual-use research of concern

In order to understand evolving US perspectives, we can consider the background of fundamental science and military use, here considered from the times from pre-World War II (WWII), during WWII, and post-WWII. Before WWII, US physicists collaborated across national boundaries in many areas, such as physics. New tools like accelerators were built to address fundamental research in nuclear physics. Visiting scholars from various institutions crossing borders for extended periods were a fact. Through the run-up to and entry into WWII, scientific responses to military problems were developed, and many international collaborations dissolved. Also, many scientists emigrated to the USA and participated in war-relevant work in secret locations. Following WWII, the scientific landscape in the US changed, with new government funding for science at universities, the establishment of national laboratories (with some addressing civil research only while others addressed both civilian and military research for national security). New guidelines and constraints were introduced to cope with the emerging Cold War environment, such as loyalty oaths and fellowships for the service to the nation. Over time, scientist-to-scientist exchanges and globally collaborative projects were re-established. Part of the plan was to preserve national technological advantage, while still developing cross-border scientific exchanges, e.g. between two major powers: the USSR and the USA. These policies evolved according to political and economic pressure as well as to cope with additional emerging international scientific leaders and new technologies that needed international cooperation. Today, the policies are, of course, influenced by the desire to safeguard technological advances and preserve economic strengths, while pushing scientific frontiers. Under them, international scientific collaboration can be set on subjects that are of mutual benefit due to their fundamental nature, enormous costs, and intellectual challenge.

However, in our rapidly growing and information-sharing world, it is often not easy to know with whom one is really collaborating. Specifically, universities and research institutions might not be well equipped to properly vet collaborations (agreements, MOUs, students and visiting scholars, etc.). Also, it may be useful to reiterate the US national policy on “the transfer of scientific, technical and engineering information”, implemented by presidential action in 1985, which clearly delineated the separation of publishable open science and classified work[1]. However, research that maybe relevant for security purposes may also benefit from open research. Because the issues of collaboration and intellectual property, and more generally professional conduct, especially those pertinent to sensitive areas, is now acute, universities and government funding agencies are rethinking policies and procedures to appropriately vet collaborations and to understand with whom the collaborations shall be carried out.

In order to deal with broader issues of research, a "Joint Committee on the Research Environment" (JCORE) was recently formed at the White House Office of Science and Technology Policy, with representatives from funding agencies, to consider guidelines for future collaboration and related topics. Part of the consideration is to ensure that US research results can be exploited in the US and that the risks of malign exploitation are mitigated.

Contrary to some concerns expressed at the European XFEL expert meeting, the engagement of scientific institutions with "dual-use" science is often recognized to be important in maintaining the quality of, and a pipeline of qualified scientists for, greater global security.

The success of the scientific enterprise of any nation requires maintaining a balance between being "openly collaborative and securely competitive". Discussion and codes of professional conduct are helpful in finding this balance. The US National Academy is also convening experts and stakeholders in round-table discussions to assess risks, identify benefits, and examine policy responses.

A Russian view on collaboration in view of new foreign policies

The international Joint Institute for Nuclear Research (JINR) located in Dubna was taken as an example in regards to collaboration. The institute has 18 members, including six member states from the European Union (EU). Cooperation with some international partners is becoming increasingly difficult. The effect of the changing new foreign policies from some long-standing collaborative partners was described. For example, it has become more difficult for Russian scientists to visit the partnering laboratory in the USA (much longer process to deliver US visas) or vice versa (no authorization by US authorities for national laboratories colleagues to attend joint meetings in Russia). Scientific conferences cannot be held on Russian soil if one desires the participation of US colleagues from national laboratories. Delocalization in an EU country might be necessary to ensure the success of a conference. In contrast to the US and Canada, the cooperative links to European and Asian scientific communities remain close, fruitful, and efficient. A general question arose regarding when one of the parties of an existing collaboration changes its foreign engagement policy to restrict collaboration with one or more of the other previous collaborators. That party may then find it difficult to continue participating in that

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[1] National Decision Directive 189, "National Policy on the Transfer of Scientific, Technical and Engineering Information," September 21, 1985, https://fas.org/irp/offdocs/nsdd/nsdd-189.htm

collaboration with the same level of transparency. Even in the present political environment, JINR-Dubna, being an international intergovernmental organization, is taking the opportunity to start new cooperative projects with additional partners from all over the world.

A Chinese view on international scientific cooperation

The presentation focused on the benefits of scientific collaboration, especially when addressing global concerns, like the challenges posed to address the global sustainable development of human societies at large (clean water, energy, manufacturing, etc.) as well as boosting the number of women in research. In order to address major risks and challenges, it is seen that the scientific community must uphold the spirit of openness and inclusiveness in order to achieve win–win cooperation to promote scientific progress at large. Science as part of society must take on its share of social responsibility. Moral and ethical norms must be respected to ensure that collaborative research stays open. China has, since 2013, invested massively in R&D (in 2018, about 290 billion USD), and the Chinese Academy of Science (CAS) is playing an important role in partnering and promoting worldwide innovation and scientific progress. There are several international science programmes and big science facilities that build a platform for scientific cooperation. CAS has established strategic cooperative relations with more than 90 research institutes and universities in 45 countries. China's new scientific infrastructures shall benefit from domestic research as well as from international cooperation. Those research infrastructures (RIs) have no dual-use purposes, and all the basic scientific research are open and publicly available.

A European view on international collaboration in today's context.

For an international scientific collaboration to be successful, some prerequisites are necessary. Without being exhaustive, the following can be listed: freedom of research, freedom to publish, freedom of travel, sufficient resources, and free access to research infrastructures (RIs). Europe has, through its Horizon 2020 programme, set a target to have open collaboration. Germany, through its various learned societies, has established international programmes.

Such international collaboration will be affected by external factors, such as political conflicts, trade wars, lack of resources or access to them (RI being a resource), and the need to increase national security that may see areas of research falling under dual-use/sensitive research or development.

Following the legal requirements (e.g. export control) is the duty of the scientific institutions, but individual scientists must also act responsibly. Adhering to and following an ethical code of conduct is essential and can build a climate to foster responsible behaviour.

In order to help institutions set up their control processes, learned societies may be able to offer recommendations. Under those conditions, international collaboration may thrive.

However, one should be aware of the pitfall of overregulating and thereby creating a bureaucratic system that will hamper the ability of setting up international cooperation or, if by law (due to risk mitigation), menacing the freedom of research. Ethical concerns of a society well used or misused for political reasons can also hamper the development of science and the freedom of research that is, for Germany, guaranteed by its constitution in Article 5.

Dual-use and export-control systems: Balancing science and security

by Jonathan Bagger, TRIUMF, Vancouver, Canada

In the talk, several examples of successful—and less successful—dual-use and export-control systems were offered, drawn from the speaker's experience as a professor and administrator at Johns Hopkins University in the USA and as laboratory director at TRIUMF in Canada. The basic theme was that clarity drives compliance, while confusion causes chaos.

The talk at the expert meeting started with a review of the bright and therefore clear line between classified and unclassified research, which worked quite well in the USA and in Canada during the Cold War. Software licenses and the regulation of special nuclear material were also discussed. In each case, the line was bright, so the requirements for compliance were clear.

Often, however, the line is not quite so bright. The example of "sensitive but unclassified" information was cited, which is becoming increasingly prevalent, especially in the realms of public health and safety, critical infrastructure, and personal information. In Canada, the rules governing this information are relatively clear, but, in the USA, they are far less clear. In the USA, regulations can differ substantially from agency to agency, which makes compliance significantly more difficult.

Canada's Controlled Goods Program, which regulates military and certain dual-use materials and technologies, was then described. Because of Canada's long-standing defence alliance with the USA, the Canadian and American programmes are aligned, and TRIUMF is audited for compliance by US officials. It was stated that this actually works to the benefit of TRIUMF, as the laboratory, through its commercial arm, TRIUMF Innovations, is able to sell beamtime to global aerospace firms for (unclassified) electronics testing and development.

Export controls apply to knowledge as well as to goods. Here, compliance is more difficult to track, especially for an organization like TRIUMF with over 1000 outside users from countries across the globe. For example, international conference presentations, international phone calls, and website downloads are all potentially subject to export control. Fortunately, TRIUMF benefits from the “fundamental research exclusion”, which means that its research is exempt so long as it leads to publication.

It was pointed out that intellectual property poses similar challenges. In an earlier era, TRIUMF was encouraged to disseminate its technology and expertise broadly. Now, it is expected to safeguard its intellectual property for the benefit of Canada. TRIUMF Innovations is building awareness and strengthening controls, all while respecting the institution’s fundamental research mandate. Cybersecurity has also moved to the fore for a host of reasons, including the protection of our intellectual property.

Export-control and intellectual-property concerns are real and increasing. The laboratory ignores them at its peril. On the flip side, the open exchange of scientific information is essential to progress. During the Cold War, scientific exchanges helped keep the peace. Even today, the SESAME light source represents a beacon of hope in the Middle East. In the talk, it was argued, therefore, that the risks should be acknowledged and respected but also that clear boundaries and advocacy for openness should be sought wherever and whenever possible. A rational balance is required. With clarity comes compliance.

Societies are facing enormous challenges: climate change, food security, clean water, human health, sustainable development, income equality, etc. Many of these issues are global in nature, and solving them will require substantial international communication, cooperation, and collaboration. Some, but not all, of the solutions will rely on technology. Scientists are being called to address these challenges. The scientist’s work is international, so we have a special responsibility to face them together. We have done this before, and we must rally to do it again. The world is counting on us.

You have to build trust with your partners

By Sandra Biedron, Element Aero, USA

It takes years to build relationships of any kind. For services in one's home, such as plumbing or carpentry, you usually ask someone with whom you already have a relationship for a referral. You might secure a person's name and still ask for their additional references as well. In a business investment, with a person or a company or stock, you take your time to study the situation. A bank uses data on a person (e.g. number of years with the bank, average funds in the account over time, any defaults) to determine if they are worthy for instance for a loan. Friendships too are built on trust and, as many of us know well, may take years, even decades, to develop.

In our own homes, in our own country or territory, many of us lock our own doors and windows. Many of us have some form of home security system. Many of us place our money in the bank. The same holds true in one's science house.

Bidirectional professional relationships, where both parties are seeking true intellectual exchange and collaboration, are built on trust, and this too can take years, if not decades, to develop. It requires a lot of patience and close personal contact between the various collaborating persons from various institutions and a great deal of transparency. Such frequent and close contact also helps one to understand what one's colleagues' work is about in its entirety, how they might view their research or do their research, as well as their career goals. This understanding can help to determine if an activity could be of dual use, inadvertently of dual use, or might be an issue for some other safety or security reason. To illustrate those points: one shall not assume that research funded by a military or security branch of the government is for direct military application. It is well known that many agencies, like the Office of Naval Research (ONR), although seemingly purely military, have basic research programmes that are not specific to military applications. More than 60 Nobel laureates were sponsored by ONR funding, and this funding was from their basic research portfolio [1]. Ironically, one of the ONR-funded Nobel prizes was Leon Cooper's theory of superconductivity [1,2]. This is the same theory that allowed us to build the European XFEL and FLASH accelerating cavities. We must, of course, be cautious in determining whether research is civilian or military. One way is to examine the funding stream compared to the Technology Readiness Levels (TRLs) [3]. For example, US Department of Defense (DoD) funding is actually specifically coded as basic research if it is in the TRL 1, 2, or 3 levels (see Figure 3). Fortunately, much information is publicly available to guide us in doing such assessments (see "Multilateral Nonproliferation Export Control Regimes" in the "Extended bibliography" section). With those conditions fulfilled, the collaboration will be fruitful and science will shine through. "Open" does not mean everything is up for grabs by anyone "off the street"; it means open for civilian use only and publishable as such.

1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high fidelity laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space).
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Source: GAO simplification of agency documents. | GAO-16-410G

Figure 3: US Government Accountability Office – Technology readiness levels

Even when technologies are established to help build safety and security, such as cryptocurrency, there are always people who will find bad in the good and use it for criminal activities. We cannot protect against everything. For example, most shops do not strive for zero shoplifting but rather work to minimize it to a “reasonable” level, using a cost–benefit analysis.

Following the same principle, a mechanism must be in place to protect the institutional assets from dual use, the malicious use of ongoing research that is intended to be publicly beneficial, conflicts of interest, and intellectual property (IP) issues:

- **Layered security**, including cyber, plus active regular training and open discussions is key to protecting the assets of a company, laboratory etc. Institutions and staff must be aware that in this technological savvy time of interconnectivity and with enough resources, it is easier to misuse or have (perhaps illegal) access to data before anyone locally can realize there is a dual-use application or an economical value (IP value).

  Even if a rushed publication is made, damages could already be done if someone had misused a concept or result. A clear concept of security: layered security must then be in place to avoid unwanted leakage of data. Many examples from private and public life illustrate the point that a lack of layered security or following the procedures too loosely can result in important damages to assets that are considered crucial.

- **Data science** is changing quickly, and new facets must be considered when addressing software, algorithms, and the use of advanced tools such as artificial intelligence (AI). See "Ethics in Artificial Intelligence" in the "Extended bibliography" section.

- **Training** regarding dual-use examples; misuse of concept, material, etc.; and identifying conflicts of interest and IP issues are often intertwined.

Export control does not cover everything; use your own experience (awareness is key), know-how, and a procedure to decide about the sensitivity of your research/technology.

- Just because something is not on the export control list does not mean it is not a concern.

- A procedure will help even a non-dual-use expert in identifying something that might be sensitive.

- Experience is gained when one is trained by an expert and is given expert guidance through the years. In safety, all of us in laboratories discuss safety incidents as a way of continuing education and to define well thought-out prevention guidelines. Dual use and security issue should be openly discussed in a similar manner.

- Institutions, like people, learn from errors made by others and work to prevent incidents from happening in their own science house. In diversity, we share examples of how others made mistakes and also examples of "wins." One should do the same for dual-use technologies and dual-use–enabling research. It should be a priority to share and discuss these errors or weaknesses during group and team meetings.

- The key is to secure expert guidance and do training for all staff. This will raise awareness among the staff.

Simple training and simple rules—looking to other procedures and training:

- Having simple and lean guidelines or procedures and specialized training has been proven to be so effective that many of us have put them into practice in our lives. Some of these general concepts are transferrable to the concerns we have regarding a member of the research community accidentally or intentionally being out of compliance with the organization's rules.

- Derive your policies from established policies, such as U.S. cryptography or open-use policies (see the "Extended bibliography" section).

- Training sessions tend to overemphasize on "what not to do", while a good balance between "what not to do" and "what to do" is crucial to understanding the issues well and reacting appropriately. Such a balance fosters creativity and allows parallel scientific development in an area that may be considered off limits.

- Another level of education can be instigated. Ethics classes/seminars at the undergraduate and graduate levels at local universities could be initiated with input from research infrastructures and industry. Creating discussions groups or having a forum where laboratory members and users can discuss hard subjects in science and engineering as well as their solutions could create additional trust and initiate further collaborations.

In everyday life, everyone practices layered security to prevent assets from being compromised, e.g. by removing the keys from the car, locking the car, having an ignition inhibitor on the motor, having a garage, having a steering wheel lock, etc. These are simple steps to prevent auto theft. The right training, the right procedures, and the right collegial work environment is the best option to keep everyone honest and to avoid mistakes, as long as they are applied consistently and without derogation. With those in place, the institutions decrease the possibility of dual-use research (intentionally or unintentionally) being carried out on their premises as well as the possibility of participating in other places as bystander collaborators.

Hence, we must start from an initial statement of policy and then allow a set of practices to evolve over time. Since these are/will be institutional policies, they can always be tailored, based on lessons learned and present-day circumstances. The ultimate goal is a focus on education and raising awareness to those not necessarily trained in security and defence considerations. In no way, shape, or form do we want to categorically exclude portions of the user community through a strict, rigid, "non-living" policy document, as working on scientific problems together, especially internationally, creates additional understanding. There are many excellent, readily available references to guide us through the questions of dual use. One can look to existing published materials to help navigate and understand the dual-use issues. Those many provided references, like the US Congressional and National Research Council reports, have been added to the "Extended bibliography" section at the end of the document. Learning from these guidelines will enhance team-building as well as research output.

References

[1] All ONR-Sponsored Nobel Laureates
https://www.onr.navy.mil/en/About-ONR/History/Nobels

[2] Leon N. Cooper – Biographical. NobelPrize.org. Nobel Media AB 2020. Wed. 25 Mar 2020.
https://www.nobelprize.org/prizes/physics/1972/cooper/biographical/

[3] Technology Readiness Assessment Guide, U.S. Government Accountability Office
www.gao.gov/assets/680/679006.pdf

Summary of the parallel sessions:
Scientific/technical issues—Relevance and application

In order to reflect on the topics presented above, balancing open-science collaboration and security (national and institutional) with its link to export control, four working groups were formed to answer a set of questions and topics relevant to FELs and dual use. Background (scientific or legal) and geographical diversity were at the core of the composition of each of the four groups. The topics of each session were introduced by a set of keynote speeches and the following debate moderated by an expert in the field addressed assisted by a rapporteur.

As a reminder the four topics of reflection (see the "Introduction to the FEL dual-use expert meeting" section at the beginning of this document) were:

1) FELs and directed-energy weapons (DEWs)
2) Superconducting (SRF) accelerator and photon system technologies
3) FELs and isotope separation
4) FEL science: Materials under extreme conditions and other science

Before coming to key questions that were asked to be reflected upon by the participants, one may want to develop briefly the reason that led the organizers to choose the four topics mentioned above:

1) Since the early 1980s and the push of the "Strategic Defense Initiative" (SDI) launched under the Reagan administration, FELs were considered a potential military weapon, either space- or earth-based, and to be eventually installed on navy warships [1]. Today, FELs are still listed as a potential directed-energy weapon (DEW) [2].

2) One of the issues is linked to technology needed to build a FEL. The accelerator technology is based either on a normal conducting radio frequency (RF) system or on superconducting RF system (see the "Principles of FEL science and technology" section). Both of those basic technologies are at least 25 years old, and much of it has been published in the literature. Nevertheless, some of the processes to form, clean, and construct such an RF structure might be complex enough that it could be subject to export control. The same is true for the photon systems dedicated to control the X-ray beams towards their targets and to detect them. In this framework, it is important to look at the relationship of the technologies developed or used to develop such systems in view of the export control laws.

3) FELs are also viewed as a potential means to separate isotopes, and one has to understand the connection between X-ray FEL machines and other FELs in the context of non-proliferation of atomic weapons and its infrastructure.

4) Finally, the last topic is about the science addressed with FELs. In some cases, the phase space that scientists may want to investigate can fall under sensitive areas of research that may have direct military applications. This last group's reflection aims at identifying areas of science that may be of concern.

Each group was asked, as mentioned above, to think about the following questions not with the intent to limit the discussions, but to stimulate the conversations:

- Can we identify potential dual-use issues in the FEL science and technology (S&T) area? To what extent and under what circumstances are FELs and/or FEL technologies relevant (and sensitive) for security- and military-related applications?
- Can we assess the seriousness and consequences of the considered cases in terms of proliferation, stability, and/or even weaponization risks?
- What are ways to mitigate or minimize dual-use risks or to limit proliferation risks for harmful applications by adversarial states or non-state actors?
- Do we need to put certain areas of FEL S&T under stricter control and which areas have to be considered?

The results of the work of each group is presented on the following pages.

References

[1] "Directed-energy beam weapons", Adelphi Papers 27 (221), 7–21 (1987) doi:10.1080/05679328708448812

[2] UN Report A/73/177: "Current developments in science and technology and their potential impact on international security and disarmament efforts" (2018)

1) Free-electron lasers (FELs) and directed-energy weapons (DEWs)

By E.M. Campbell (U. Rochester), M. Ferrario (INFN), and H.-A. Eckel (DLR)

Key message: FELs in general will play *no* role for the foreseeable future in the development of directed-energy weapons.

Introduction

The concept of a directed-energy weapon (DEW) was first introduced by H.G. Wells in his classic short story "War of the Worlds" [1]. DEW weapons concentrate and direct their energy into a small solid angle in contrast to conventional explosives that nominally release their energy in all directions. In this story, the Martians used a directed "heat ray" weapon against humankind in their invasion of Earth.

Such weapons remained as part of science fiction until the demonstration of the first laser by Maiman in 1960 [2], exploiting a concept developed by Townes, Basov, and Prokhorov, who were awarded the Nobel Prize in Physics in 1964. The laser—which is short for light amplification by the stimulated emission of radiation—relies on the process of stimulated emission first proposed by Einstein in 1915. Soon after the demonstration of the laser, militaries around the world initiated research into the development of DEWs motivated by their ability to project energy at a distance at the speed of light (~3 x 10^5 km/sec or about 10^6 times faster than the speed of sound). Since the first demonstration, lasers have become essential components in modern life and have enabled an enormous number of applications in industry, commerce, medicine, science, and the military (active sensors, ranging and targeting, etc.). In addition, a number of laser concepts have been successfully developed using solid, liquid, gaseous, and plasma media. Such lasers now span wavelengths from the soft X-ray to the mid infra-red regions of the spectrum, pulse durations from femtoseconds (10^{-15} seconds) to continuous operations (CW) and powers from microwatts (10^{-6} watts) to petawatts (10^{15} watts) [3].

In addition to these lasers, which involve bound energy states of atoms, ions, or molecules, the free-electron laser (FEL), which employs stimulated radiation from relativistic free electrons undulating in a periodic magnetic field, was demonstrated in 1976 [4]. Since the first demonstration, FELs have shown rapid development with output wavelengths now ranging from the X-ray to the infra-red region of the spectrum. Because FELs do not utilize bound states, they are able to operate over a wide range of wavelengths and pulse lengths; as a result, they have become versatile and capable tools for scientific research.

Requirements for DEWs

For any technology to become militarized and advance to a weapon, it must satisfy stringent requirements [5]. For example, it must be cost-effective, not prohibitively large, and able to be deployed and used in a battlefield environment. For DEWs, a useful metric for evaluation is the “SWaP” (size, weight, and power) of the overall system. For lasers, this includes the gain media, optical components, and the subsystems to energize and get rid of the excess heat produced during lasing. (Lasers are relatively energy inefficient devices, with typically only ~30% of the input energy emerging as a directed beam of photons.) SWaP is an essential metric for determining which platform can be used (plane, ship, satellite, ground vehicle) and the mobility of a DEW.

There are also additional requirements for DEWs that must be incorporated into any SWaP analysis. Since one of the attractive features is the delivery of concentrated energy at distance, DEWs must have very good beam quality—i.e. a near diffraction-limited beam emerging from the final aperture. If the weapon is to be used near the ground or at low altitudes, only certain wavelengths that can propagate through the atmosphere can be used.

The power/brightness of the DEW also depends on the application. These generally fall into two categories: tactical and strategic. Tactical applications can be defensive—including aircraft, ship, and military base protection—and offensive against high-value targets, where collateral damage is to be minimized. These are generally short range (~10 km or less) and have desired output powers in the ~50 to 100 kW range. Strategic applications have generally been directed to missile defence, specifically when they are in the “boost phase” when the rockets—which are more vulnerable to laser energy than the re-entry vehicles that carry the payload warheads—are firing and the payload(s) are not yet deployed. The range of engagement is now hundreds of kilometres, and the laser powers are hundreds of kilowatts to megawatts.

It is worth noting that, in the early days of the "Strategic Defense Initiative" (SDI), ground-based lasers, including FELs, were considered for missions against satellites and other space-based assets. Such lasers would have reduced requirements on SWaP and the challenges of operating in a combat environment, but challenges of cost, complexity, and input power requirements still remain. In addition, propagation through the atmosphere (including clouds, absorption, etc.) is a major challenge for any ground-based system. For all of these reasons, such missions are no longer being considered for DEWs.

With this background in mind, military research has developed a set of criteria for DEWs. These are summarized in Table 1 [6, 7].

Topic	Performance	Comment
Power	~100 kW (tactical) ~1 MW (strategic)	
Beam quality	$M^2 < 2$	M^2 is a measure of beam quality. M^2=1 is diffraction-limited, the highest beam brightness determined by laser wavelength, aperture size, and focal length.
Wavelength	~0.7–2 μm	Atmospheric transmission.
Efficiency	>30%	Prime power (electrical) to output beam.
Specific weight	~1 kW/kg	Output power per mass of overall system (energize, thermal management, optics, gain media).
Integrability	Modular	System components are to be separated.
Logistics	Simple	Minimal extra burden to deploy in hostile environment.
Energy supply	Electric	"Large magazine depth".
Operational environment	Vibration, shock, dust, etc.	Robust in hostile environment.

Table 1: Desired Performance Requirements for DEWs

FELS as DEWs

FELs have in principle several attractive features that motivated research for a possible DEW application [4]. They are electrically powered, have wavelength agility (Table 1), and the potential for high output power. In addition to these attractive features, the other competition for high power was primarily limited to chemical lasers (the laser action is initiated by chemical reactions), such as the Oxygen-Iodine (COIL laser) and deuterium-fluoride lasers. CO_2 lasers were also initially developed for DEW applications, but the long wavelength (~10.6 μm) and other issues ended research by the US in the early 1980s. As a result, when President Reagan initiated SDI ("Star Wars"), research on FELs was initiated [8].

At the end of President Reagan's term and following the collapse of the Soviet Union, SDI research was significantly reduced and with it a concomitant reduction in FEL activities. In addition, and very importantly, the development of high power, efficient laser diodes, fibre lasers, beam combining, and novel cooling methods enabled the rise of "solid state" lasers that have the potential to meet the demanding requirements outlined in Table 1 [9, 10]. While there was a renewed interest by the US Navy in the first decade of this century for FELs for ship defence [11], the continued development of diode-pumped fibre and solid-state lasers and the realization that the SWaP for FELs poses enormous challenges led to the conclusion that FELs for directed energy research were **no longer** interesting. While not completely current, Figure 4 illustrates the growth of solid-state laser (both finite aperture (SSL) and fibre lasers) power over time and shows that they are now, or soon will be, reaching power levels of interest for DEWs.

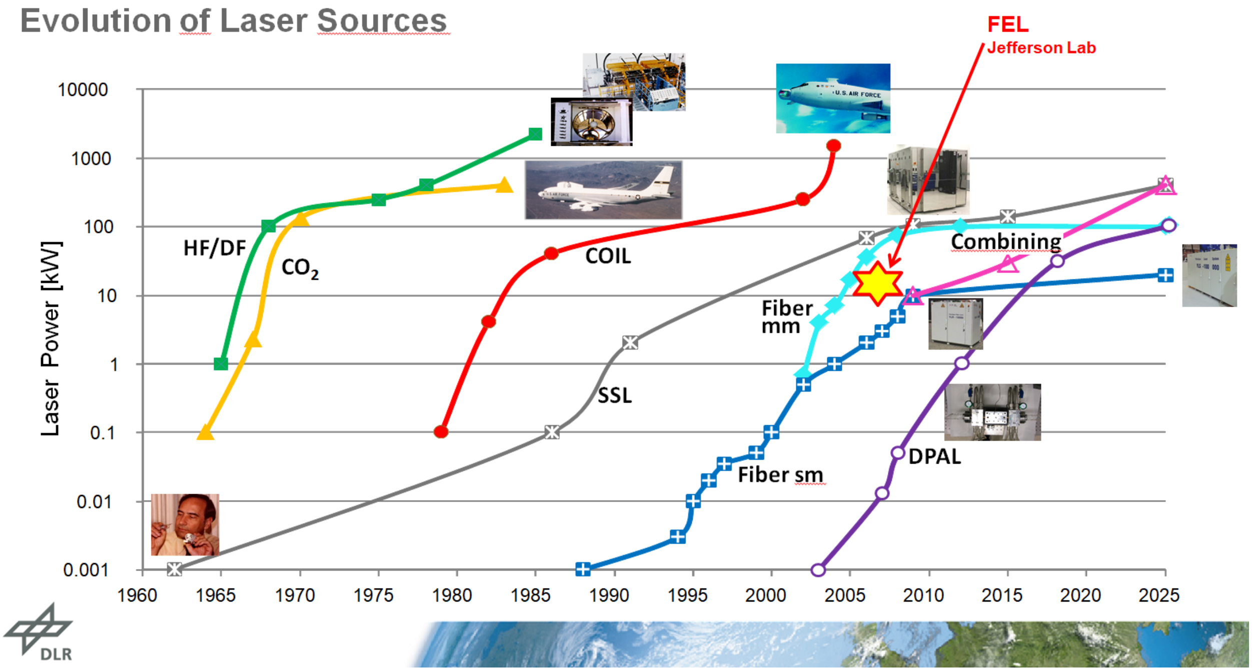

Figure 4: Laser output power levels (kW) as a function of time [6]

While not solid state, the diode-pumped alkaline laser system (DPALS) in Figure 4, [12] is energized by high-power laser diodes. Also shown in the figure is the largest output power reported for an FEL of ~13 kW, demonstrated at the Jefferson Laboratory [13].

While the performance requirements listed in Table 1 have not yet been met, significant research and development is ongoing for these solid-state lasers, and there are credible paths to achieve the demanding requirements for deploying DEWs. Research also continues on the DPALS concept.

In summary, while in principle FELs could be developed as DEWs, in practice the SWaP and other features of Table 1 along with the development of far more attractive solutions, eliminate this "dual-use concern" of FELs for the foreseeable future.

References

[1] H.G. Wells "The War of the Worlds", Publishers William Heinemann (UK), Harper and Bros (US), 1898

[2] T.H. Maiman "Stimulated Optical Radiation in Ruby," *Nature* **187** (4736), 493–494

[3] M. Bertolotti: *The History of the Laser* (Institute of Physics Publishing, pp. 226-234 and references within, 2005)

[4] L.R. Elias et al.: "Observation of Stimulated Emission of Radiation by Relativistic Electrons in a Spatially Periodic Transverse Magnetic Field," Phys. Rev. Letters **36**, 717 (1976) doi:10.1103/PhysRevLett.36.717

[5] A. Feickert: "U.S. Army Weapons Related Directed Energy (DE) Programs: Background and Potential Issues for Congress", Congressional Research Office, February 2018

[6] Hans-Albert Eckel: Personal communication, DESY Conference on Dual-uses for FELS, November 2019

[7] Laser Weapons Systems, "Speed of Light to the Flight by 2020," AFRL report, December 2016

[8] "Free Electron Lasers and other Advanced Sources of Light: Scientific Research Opportunities," National Academy of Sciences Press (1994)

[9] P. Sprangle et al.: "High-Power Fiber Lasers for Directed Energy Applications," Applied Optics **54** (31), F201–F209 (2015)
doi:10.1364/AO.54.00F201

[10] G. Warwick, "General Atomics Third -Gen Electric laser Weapon Now Ready," *Aviation Week & Space Technology,* 20 April 2015

[11] Office of Naval Research: ONR Scientists Collaborate on Directed Energy "Directed Energy Flagship: FEL Showcased," November 2008
https://www.onr.navy.mil/en/Media-Center/Press-Releases/2008/ONR-Collaborate-Directed-Energy

[12] W.L. Krupke: "Diode pumped alkali lasers (DPALS): A review," Progress in Quantum Electronics **36** (1), 4–28 (2012)
doi:10.1364/OE.25.009458

[13] "Scientists unleash highest energy beam ever at Jefferson Laboratory," Rdmag.com, May 2015

2) Superconducting accelerator (SRF) and photon system technologies

By H. Weise (DESY), T. Tschentscher (European XFEL), D. Wang (SARI)

Key message: X-ray technologies were not considered directly critical, but the relevance of X-rays for dual-use applications remains a general concern. Export control mechanisms are considered sufficient to deal with the dual-use problem for these technology developments.

Summary of findings

The technology developed for free-electron lasers (FELs), in particular the accelerator technology and its various subsystems, is feared by selected bodies to be of potential relevance to dual-use applications. The invited experts in the field on research with FELs therefore were collecting and discussing the available knowledge with regard to this alleged potential relevance. In particular, superconducting acceleration technology is the most effective path towards high average power accelerators. The accelerator includes various state-of-the-art subsystem technologies, like superconducting cavities, high-power radio-frequency systems, electronics, and diagnostics enabling the operation of these accelerators. The photon system technologies are equivalently state of the art with respect to the production, diagnosis, and detection of X-ray radiation.

However, the evaluation of the real potential of the FEL technology for dual-use applications requires a good understanding of military demands and applications. Such understanding is not available in research organizations and will require the involvement of knowledgeable governmental bodies, internationally oriented institutions, and think tanks. The respective knowledge was not available in the discussion session and it was therefore not possible to define concrete cases or critical technology domains requiring specific attention.

Instead, the opinion was raised that one should apply the existing regulations and procedures of export control, established in most western hemisphere countries. This system works through the definition of various technology items and specific target parameters with the goals to limit the distribution of the corresponding technology as well as the dissemination of know-how. New dual-use cases and new technology developments need regular assessments in order to keep export control regulations state of the art. These assessments would benefit from bodies knowledgeable in both the corresponding technologies and their potential and the dual-use cases and potential military applications.

SRF technology and dual-use applications

The use of superconducting radiofrequency (SRF) accelerator technology for the development of military motivated FELs started in the 1980s. Until 2018, the US Department of Defense (DoD) awarded contracts to continue these developments. Similar developments may have taken place or still take place in other countries, but they were unknown to the participants of the discussion session.

A major international and research-driven effort to develop SRF accelerators is coordinated by the TESLA [1] Technology Collaboration (TTC). Based solely on a Memorandum of Understanding (MoU), this collaboration represents the scientific community and research accelerator laboratories worldwide. This collaboration has already led to several installations: FLASH and the European XFEL in Germany and LCLS-II in the USA. The European XFEL construction was a European effort with contributions from all regions worldwide (including the USA, Russia, and China). Presently, the collaboration turns towards continuous-wave acceleration with commonly agreed development foci. Measurement techniques are generally published; so far, no sensitive issues have been identified and Intellectual Property (IP) issues have been respected. It is noteworthy that China, building an SRF accelerator for the SHINE project in Shanghai, is therewith adding to the community of laboratories operating these facilities. Additionally, the Chinese Academy of Engineering Physics (CAEP) has also a keen interest in developing a high-repetition-rate machine based on SRF technology to produce high-energy photons. DESY has started joint R&D programmes with Chinese institutes from the Chinese Academy of Science (CAS), e.g. to develop large grain material for superconducting cavities. The benefits of this international collaboration will be for many large facilities worldwide (Europe: European XFEL, European Spallation Source (ESS); USA: Linac Coherent Light Source II (LCLS-II), Facility for Rare Isotope Beams (FRIB); Asia: International Linear Collider (ILC), Shanghai High Repetition Rate XFEL and Extreme Light Facility (SHINE)), for which Niobium cavities and cryostats from China already play an important role.

Since SRF accelerators and their application in high-power applications bear a potential for dual-use applications, the following aspects require further consideration:

- Accelerator-driven systems (ADS) clearly benefit from SRF developments. Usually, SRF developments are reported at TESLA Technology Collaboration (TTC) meetings, but the real expertise is at the individual research facilities like ESS and the Spallation Neutron Source (SNS) in the USA, or the Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) in Belgium. The dual-use aspects of high-power proton beam machines can only be discussed with the respective facility experts.

- Several technologies might be considered critical with respect to knowledge distribution, e.g. superconductivity technologies or cavity surface treatment. Results in this field are essentially published, and open scientific exchange has a long tradition. Laboratories worldwide have established the technology at their institutes or are trying to do so. It is considered that practical experience is more critical than theoretical knowledge.

- SRF accelerator technology supports the development and construction of high flux/power or even the construction of compact (and similarly technology-simplified) accelerators.

It was discussed that the changing international situation may lead to new requirements for technology developments like those pushed forward by the TTC. Although no direct application of SRF accelerators for direct weapons are in question, the potential of the technologies for use in dual-use applications remains unclear. With the additional question of intellectual property (IP) issues, the complexity to create governance for international technology collaborations similar to TTC will likely increase: The TTC model, based on an MoU, is probably not realistic or at least not sufficient for future collaborations. Already today, a number of bilateral agreements supplement the TTC MoU. This allows for well-defined technology transfer but also IP protection. Here, the group foresees a further need for clearer guidelines on these regulations in facilitating large international collaborations on the forefront of scientific and technological development.

Photon system technologies and dual-use applications

This area of technology development is a lot more conservative in that the new developments of X-ray instrumentation, initiated for and pushed by the FEL facilities, are rather an incremental development of technologies developed and internationally implemented within the last two to three decades. However, several developments for new detection systems and X-ray diagnostics are well beyond state of the art and may bear a dual-use potential, in particular since X-rays offer unique properties in investigating and studying materials of relevance for dual-use applications. Since the participants of this session did not possess the relevant knowledge of X-ray dual-use applications, an informed discussion of critical areas could not be conducted. However, since such knowledge should exist in bodies knowledgeable about dual-use applications, like governmental institutions and ministries, it is considered that this area is sufficiently covered by the existing international processes and regulations, in particular export control.

References

[1] TeV Energy Superconducting Linear Accelerator (TESLA)
https://flash.desy.de/tesla_technology_collaboration/tesla_documentation/

3) FELs and laser isotope separation

By W. Eberhardt (DESY), W. Fuss (MPQ), F. Lehner (DESY), and R. Snyder (IFSH)

Key message: The only known and potentially viable path for laser enrichment of uranium requires accurately tuned light at longer wavelengths (visible or IR) and not X-rays from X-ray FELs. The associated proliferation risk for X-ray FEL technology is small.

Introduction

Laser isotope separation (LIS) encompasses the processes used to separate isotopes by selective laser excitation. For molecular species, the required optical excitations for specific isotopes are sensitive to the energy levels of vibrational states, with isotopic shifts in these levels arising from differences in the mass of the molecules [1]. Such excitations occur in the infrared (IR) spectral range, and heavy elements like uranium require cooling to separate overlapping absorption bands to permit selective excitation of the desired isotope. For atomic species, separation of uranium-235 and -238 is permitted by isotopic shifts in energy levels caused by a combination of the different radii of these two nuclei and the hyperfine structure present in uranium-235.

LIS activities began in the 1970s with the advent of tuneable lasers for light elements (sulphur, carbon, oxygen, etc.) as well as for uranium using various methods. Several variants of LIS for uranium—either through resonant multiphoton ionization of uranium atoms in vapour (atomic vapour laser isotope separation, AVLIS) or through IR (~15.9 µm wavelength) multiphoton dissociation of UF_6 molecules (molecular laser isotope separation, MLIS)—have been explored [2]. Almost all commercial prospects for LIS schemes on uranium were abandoned in the 1990s or early 2000s, either due to technical difficulties or because economic operation appeared hopeless. There is one process utilizing condensation repression by laser excitation, however, that could yet prove competitive with the gas centrifuge. One variant of this concept is called "separation of isotopes by laser excitation" (SILEX) and was developed by the Australian company Silex Systems, Ltd. It utilizes one IR photon (also at a wavelength of ~15.9 µm) to excite $^{235}UF_6$ in a cold molecular beam. The unexcited heavier $^{238}UF_6$ isotopes form clusters with a carrier gas and remain closer to the axis of the molecular beam, while laser-excited $^{235}UF_6$ molecules resist cluster formation and move to the rim of the gas allowing some separation [3]. After business consortium Global Laser Enrichment (GLE) successfully demonstrated the technology in a test loop and obtained a license to operate a facility from the US Nuclear Regulatory Commission in 2012, future developments will now proceed in line with enrichment market realities. The path to commercialization may yet be more likely through the uranium mining industry, as negotiations are currently ongoing between GLE and the US Department of Energy to build a facility in Paducah, Kentucky, USA, to enrich depleted uranium tails to natural-grade levels.

There is an ongoing debate as to whether the development and deployment of SILEX laser enrichment technology presents a proliferation risk [4]. The worries are mainly due to the potentially small size and more efficient energy consumption of clandestine plants, which would make detection difficult. However, detailed comparisons of imagined setups utilizing the condensation repression approach with existing centrifuge designs show no substantial difference in the area footprint required [2, 3], but possibly substantial energy efficiency advantages [3]. On the other hand, because most centrifuge designs can already operate below the detection thresholds for area footprint and energy use, such comparisons are likely not relevant for comparing the proliferation risk of the two technologies. A far more important criterion is the accessibility and attractiveness of a technology; but, regardless of any such assessment, both routes to nuclear weapons acquisition are possible.

MLIS and SILEX methods likely use ~15.9 µm infrared laser light, which is typically produced from a pulsed, high-pressure CO_2 laser (emitting ~10.2 µm) that is Raman-shifted to ~15.9 µm for selective excitation of ^{235}UF6. CO_2 lasers are workhorses for such purposes and have advanced since the 1970s. Condensation repression may also utilize ~5.3 µm light produced from CO lasers, operating in either pulsed or continuous mode. This laser technology can provide high IR power and is rather efficient, reliable and widespread in industry and scientific laboratories. Accelerator-based free-electron lasers (FELs) might provide even higher power (both peak and average) and continuously tuneable IR light. Pulse energies and/or pulse durations depend on features of the electron beam in the accelerator structures, and continuous wave operation is also possible. However, the accelerator technologies of FELs are rather expensive and complex, and only a limited number of institutes and individuals worldwide are capable of operating such machines. Moreover, low-power quantum cascade lasers (QCLs) may also be used to enrich uranium by condensation repression; they can be tuned, combined for higher power emission, and operated in continuous-wave mode, and would be much less technically demanding to master than FELs. A serious risk with QCLs is that their accessibility is advanced by ongoing development within other desirable applications. The proliferation risk of FELs should therefore be considered small by comparison with the growing accessibility of such lasers, as well as that with CO_2 and CO lasers that currently exist.

Findings

1. The only economically competitive LIS scheme that could yet challenge the gaseous centrifuge in the uranium enrichment market relies on selective photon excitation of a specific transition of $^{235}UF_6$ using infrared lasers. Here, CO_2 lasers along with Raman-shifting cells, or CO lasers operating in pulsed or continuous mode, are likely the standard laser technologies to use, due to their reliability and ability to cost-effectively generate the required IR radiation at ~5.3 or ~15.9 µm. QCLs may have already replaced these lasers within programmes currently under development given their possible advantages, or they may do so in the future.

2. However, because the required photon energies are in the mid- to far-IR range, soft or hard X-rays generated at FELs in Hamburg such as the *European XFEL or FLASH do not play any role here.*

3. In principle, a dedicated IR-FEL based on an electron beam in accelerator structures could be used to enrich uranium, even to bomb-grade levels utilizing known separation concepts. It is also possible that this effort could be indistinguishable from other activities given the space required and energy consumed. However, the attractiveness and accessibility of this route to proliferator is reduced by the fact that a ~15.9 µm FEL would be larger, be more expensive, consume more energy, be more technically complex, and require vastly more time to install and commission than CO_2, CO, or quantum cascade lasers. Perhaps most importantly, given the limited number of FELs worldwide, access to the relevant equipment or to people with the knowledge required to successfully build and operate such an FEL would be far more limited compared to other laser routes.

4. IR-FELs may have advantages over more typical routes using gaseous CO_2 or CO lasers. For instance, IR-FELs could emit continuous beams easily tuneable to the desired wavelength with narrow linewidths. The challenge of tuning CO_2 or CO lasers to the desired wavelength and increasing the pulse repetition rate of the CO_2 laser (to avoid unirradiated gaps in the molecular beam) may give IR-FELs an advantage in the eyes of some proliferators. There may also be some technical challenges in elevating the power of CO lasers to levels capable of effectively exciting the $3\nu_3$ transition of $^{235}UF_6$, which has a significantly smaller cross section than the ν_3 transition excited by ~15.9 µm light. The possible advantages of FELs should be considered with respect to these imagined challenges, which may not currently present significant obstacles and are less likely to in the future.

5. It must be stated, however, that attempts to acquire nuclear weapons likely depend on what route is imagined as most accessible by a potential proliferator. Regarding enrichment technologies, the gas centrifuge currently dominates the international market, and this technology has already produced quantities of bomb-grade uranium for nuclear weapons in a number of states. This may suggest that this route is more attractive than LIS using powerful CO_2 or CO lasers, and especially in contrast to IR-FELs. It must be stated, however, that past failed attempts to acquire nuclear weapons with gas centrifuge technology—or any other technology for that matter—may have succeeded had countries selected or had available a different technological path. This, of course, applies to future acquisition attempts as well. In any case, limits in establishing confidence with reference to history or physical principles should be acknowledged when considering any technically viable pathway to nuclear weapons acquisition.

6. This raises the question whether detecting clandestine uranium enrichment facilities using LIS is likely to be more difficult than those using centrifuges. Aspects of LIS activities for uranium may be hidden in standard academic or industrial programmes, and detection probably has to rely on whistle-blowers or complicated and fortuitous

assessments of public domain information. Some acquisition attempts for equipment relevant to LIS may be complicated by export control [5].

7. Knowledge gained from FEL experiments at DESY and/or European XFEL using the spent THz beam or IR emission—not the primary X-ray FEL radiation—could advance ideas about how to enrich uranium. This could be, for instance, due to photochemistry experiments serving as proxies for uranium enrichment separation concepts or operating parameters. Some of these experiments, however, may not be identifiable or may advance scientific knowledge considered desirable and be worth some adverse proliferation risk. It is also worth noting that knowledge could be transferred through publishing the results of experiments in scientific journals or to others who are simply users of the facilities in Hamburg.

8. More clarity could also be gained by taking into account other technological and scientific advancements that have already occurred or are currently occurring in laser labs worldwide. This accumulating knowledge increasingly published in the public domain may be associated with greater proliferation risks when compared to research work at DESY and European XFEL. Raising awareness about these developments could provide a helpful context at DESY and European XFEL within which dual-use risks are better assessed, minimized, and communicated to others.

References

[1] R. J. Jensen et al.: “Separating Isotopes with Lasers”, Los Alamos Science **4**, 8–9 (1982)
https://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-82-5176

[2] Werner Fuß: “Laser isotope separation and proliferation risks”
https://www.mpq.mpg.de/5178012/MPQ346.pdf

[3] Ryan Snyder: “A Proliferation Assessment of Third Generation Laser Uranium Enrichment Technology”, Science & Global Security, **24**, 68–91 (2016)
doi:10.1080/08929882.2016.1184528

[4] E.M. Grossman: “Closely held report discounts proliferation risk of lasers for making nuclear fuel”, Global Security Newswire, 24 May 2012
www.nti.org/gsn/article/closely-held-report-discounts-proliferation-risk-lasers-making-nuclear-fuel/

[5] International Atomic Energy Agency IAEA: "Communication Received from the Permanent Mission of Kazakhstan to the International Atomic Energy Agency regarding Certain Member States’ Guidelines for Transfers of Nuclear-related Dual-use Equipment, Materials, Software and Related Technology”, INFCIRC/254/Rev.11/Part 2, 18 October 2019

4) FEL science: Materials under extreme conditions and other science

By: F. Le Pimpec (European XFEL), S. Pascarelli (European XFEL), and M. Svandrlik (FERMI)

Key message: Publishing data rapidly and publishing short and simple user rules will ensure proper compliance to legal constraints and deter hidden military research.

Introduction

The main and most critical area for potential “dual use” applications at X-ray FELs was deemed to be related to investigation of matter and materials at extreme conditions.

Evidence that the science of materials at extreme conditions is of potential dual-use interest can be found in the facility planning of institutions that play a role in their respective nation’s nuclear weapons efforts. At Los Alamos National Laboratory in the United States, the MaRIE project [1], now known as the Dynamic Mesoscale Materials Science Capability (DMMSC) [2], aims to address both basic science and support nuclear weapons stockpile stewardship through the development of a high-energy X-ray free-electron laser (X-ray FEL). In China, the Chinese Academy of Engineering Physics (CAEP) has plans to develop a high-energy X-ray FEL using superconducting radiofrequency (SRF) technology that shall produce high-energy photons (> 40 keV) with the aim to study the properties of bulk material [3]. It is noteworthy to stress that scientists from these institutions routinely publish high-visibility, fundamental science papers on materials at extreme conditions, including based on results obtained from international light-source user facilities.

All instruments at the European XFEL e.g. could potentially be powerful probes for the investigation of systems and processes that fall under the “sensitive” regime, i.e. in which the results obtained might be relevant to the physics and the properties of material during nuclear detonation. Because of the unprecedented intensity of the X-ray pulses, the X-ray beam itself could bring the sample into an extreme thermodynamical state that might fall (depending on the sample and on the specific regulations in a given country) into the “sensitive regime”.

We call matter under extreme conditions:

a) Matter with energy densities exceeding ~10^{11} J/m^3, known as “high energy density (HED)” matter

b) Matter subject to pressures above 1 Mbar (= 1 million times the atmospheric pressure)

There is a direct correlation between points a) and b).

These states of matter can be found in the deep interiors of planets and stars and can be reproduced in many laboratory applications, e.g. during the interaction of powerful and intense laser beams with materials.

HED science is an emerging field of research at X-ray FELs, and many are being equipped with platforms for experiments combining hard X-ray FEL radiation and the capability to generate matter under extreme conditions of pressure, temperature, or electric field using the FEL, high energy optical lasers, or pulsed magnets.

Scientific applications include studies of matter occurring inside exoplanets, of new extreme-pressure phases and solid-density plasmas, and of structural phase transitions of complex solids in high magnetic fields.

At the European XFEL, as mentioned above, all instruments may be involved in this research area because of unprecedented intensity of the X-rays. X-ray pulses can e.g. be used to isochorically heat a solid system into a plasma state, while a second X-ray FEL pulse probes its time evolution.

In addition to this, the HED instrument offers a number of different drivers, including high energy (ns pulse) and high intensity (fs pulse) optical lasers that allow to generate a large variety of extreme states of matter, up to pressures of ~10 Mbar and above, or temperatures of up to the keV (1 eV ~ 11000 K). The European XFEL pulses are used to probe the electronic and atomic structure, and their dynamics, in such extreme states of matter, both in or out of local thermal equilibrium conditions.

Some of these applications, depending on the system studied and on the thermodynamic conditions, may be sensitive.

Potentially sensitive research at European XFEL goes beyond the field of matter at extreme conditions. For example, the investigation of dynamic materials (explosives, Uranium, and surrogate metals and alloys) and processes (turbulent material mixing, solidification, phase transformations, interfacial microstructure, and strain evolution) at both the micro and mesoscale could help advance the frontiers or materials research and potentially contribute to the understanding of weapon performance.

This is a new area of applications, not tackled today, and an X-ray FEL providing at least twice the photon energy of what European XFEL is yet producing would address this research field. Based on such facility, Figure 5 shows the science at mesoscale that will be tackled, and, from its understanding, one can comprehend the material performance and its production.

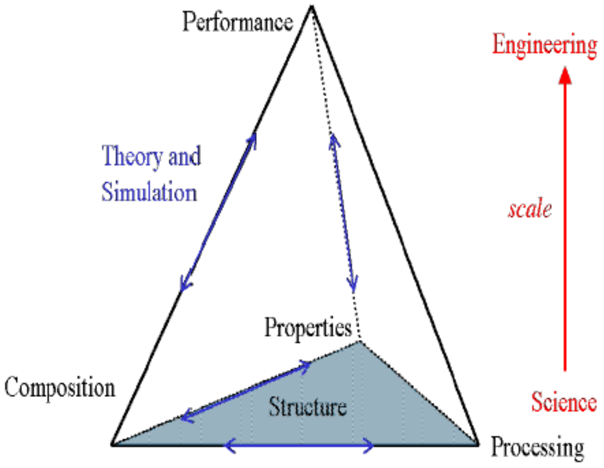

Figure 5 Understanding material properties for usability in the technological domain. Courtesy of John Sarrao (LANL)

Biological systems may be investigated that fall into a similar "sensitive" domain as well. These domains have been clearly identified in the "Fink report" [4], but the connection between X-ray FELs and dual-use in biology research at a beamline might not be that obvious, in the absence of a Biosafety Level 3 or 4–type laboratory [5]. These types of laboratories allow the safe study of biological materials (bacteria and viruses) that may have a lethal outcome when being infected. However, one shall not forget the potential link to materials science or aerosol physics that might ease toxin deliverable [6], and one strong point of X-ray FELs is the study of advanced material.

X-ray FEL and FEL pulses in general allow the retrieval of the atomic structure of "nano" (nm-sized) crystals of proteins and of radiation-sensitive crystals. The X-ray FEL beam has the potential to also allow the study the conformation of non-crystallized proteins. These new opportunities widen the domain of applicability to families of biological systems that are difficult to crystallize or that do not crystallize at all. Understanding the structure of a protein is key to understand its function. Moreover, by exploiting the short pulse duration coupled to pump–probe methods, it is possible to reconstruct atomic movies of proteins during a chemical reaction or a biological process.

An additional potentially sensitive area of the application of X-ray FELs is the investigation of chemical processes. In chemistry, a FEL, with its short and intense pulse, can provide a snapshot during the transient of a chemical reaction. Understanding a reaction at the atomic scale and at the relevant timescales opens the doors to modifying it and obtaining a different/modified compound than the reaction would normally provide.

All of the above can have applications outside the civilian domain, and understanding the "risk area" of dual use is challenging.

The topic *material under extreme conditions* was emphasized during this session, as it touches the proliferation issue. In the absence of nuclear testing, access to data on material properties such as those that can be provided by X-ray FELs (as well as other facilities) is important in order to underpin the calculations that assess the safety and performance of modern nuclear weapons. Two keynote scientific talks on basic research addressing material under extreme conditions set the scene. One of them also emphasized that, despite the fact that the field has direct impact on national security, international collaboration was essential to advance the frontiers of science.

For HED, the discussion led to looking for some ways to avoid dual-use issues for the field:

- Raise awareness of areas of potential sensitivity for proposed experiments.
- HED proposals that might be potentially sensitive could be flagged, and the proposers might be required to provide a certification from their institution that the proposed research is suitable for an open facility and would be in accordance with all institutional or national security restrictions. This would enforce accountability for all researchers coming from institutions that deal with classified or sensitive information.
- The problem of screening the proposals for sensitivity was discussed, and there are no universally agreed guidelines. However, in Europe, the French CEA has released, for the usage by civilian researchers of its Megajoule Laser (LMJ) [7], the area permissible for experimentation and a chart for sensitive research [8].
- This led to the question of whether there would be a wish to consider this foreign guideline to identify possibly sensitive experiment proposals for HED at the European XFEL. If so, obtaining a certification by the proposer institution or consortium might become necessary, as mentioned already. This shall not preclude that other investigations are conducted to ensure compliance and that no dual-use research is carried out in the facility.

One of the conundrums of these three points is that it assumes that researchers or reviewers may have nuclear weapons experience to be in a position to judge whether a given proposal posed unacceptable dual-use risks. The information necessary to know whether a given experiment might yield sensitive information is itself sensitive.

General findings

In order to avoid studies that can lead to promoting proliferation, some clear rules can be laid out. For example, rules have been laid out in the usage of the LMJ in France [8] or in the USA [9]

European XFEL can decide for its guideline and if it wants to:

1. Allow all research related to matter under extreme conditions, except for obvious material like Plutonium. One can understand and allow the study of Uranium in the ratio U235/U238 used in commercial nuclear reactors.
2. Allow research only under some regime of pressure, temperature, and atomic number.

3. Deny all research access that is directly relevant to military research, with the caveat explained in the keynote "You have to build trust with your partners" for research institutions that seemingly are doing military research but may not be. One can look at the funding or at the TRL level of the research, as mentioned in "You have to build trust with your partners".

On the last point: It may not be possible to properly enforce such tight control, as some independent, innocent research, when coupled together, can be used directly for military applications. In this case, the check would be done regarding the background of the users and their publications to understand the end motive. Additionally, it was noted that some research on innocuous materials can serve as benchmarking for sensitive material study through code validation.

Two categories that can be difficult to detect without deep knowledge in weapon-related research are:

- "Proxy experiments", i.e. experiments that either use materials or methods, or both, that are clearly not in any way weapons-related, but whose successful completion can inform weapons-related work.

- Fundamental research in the overlapping domains of high-performance computational physics and experimental material science. Recognizing the kinds of basic research that needs to be carried out requires knowing the details of the phenomenological models underpinning weapon research that shall be replaced by first-principles models.

Here again, a cross check on the intent of the work, background and the detail funding source of the user would be needed. In both cases, it is very unlikely that a civilian facility such as the European XFEL could carry out such a check.

Finally, the group addressed some of the topics of the second day regarding actions that could be undertaken to create policies and guidelines and the responsibility of the scientists and the institutions for which they are working for. These are reflected in the "Summary of the discussions on transfer into governance, policies, and legal " section at the end of this document.

References

[1] MaRIE: Matter-Radiation Interactions in Extremes
https://www.lanl.gov/discover/publications/_assets/docs/FINAL-LALP-10-059-reduced.pdf

[2] Los Alamos National Laboratory: "Dynamic Mesoscale Material Science Capability"
https://www.lanl.gov/science-innovation/science-facilities/dmmsc/index.php

[3] X. LI: "Progress on Collaboration between CAEP and European XFEL /DESY /HZDR" international conference on CAEP-EUXFEL Collaboration and Communication Oct. 2018, Mianyang, China.

[4] National Research Council: *Biotechnology Research in an Age of Terrorism*, Washington, DC, The National Academies Press (1994)
doi:10.17226/10827

[5] UKRI, Medical Research Council: “Do You Know The Difference in Laboratory Biosafety Levels 1, 2, 3 & 4?” (2015)
https://consteril.com/biosafety-levels-difference/

[6] Medical Research Council: Managing risks of research misuse
https://mrc.ukri.org/research/policies-and-guidance-for-researchers/managing-risks-of-research-misuse/

[7] The French Megajoule Laser Project (LMJ)
Fusion Engineering and Design, Volume 44, Issues 1–4, 1, 1999
https://www.sciencedirect.com/science/article/pii/S0920379698002658

[8] http://www-lmj.cea.fr/docs/2017/LMJ_PETAL_Users_guide_v1.3.pdf

[9] US Department of Energy: “Draft Public Guidelines to Department of Energy Classification of Information” (1994)
https://www.osti.gov/opennet/forms?formurl=https://www.osti.gov/includes/opennet/document/guidline/pubga.html#ZZ1

The University of Chicago Institutional Oversight of Life Sciences Dual Use Research of Concern (DURC)

By Joseph Kanabrocki (U. Chicago)

Overview

Dual-use research of concern is a subset of dual-use research defined as

> "life sciences research that, based on current understanding, can be reasonably anticipated to provide **knowledge, information, products, or technologies** that could be directly misapplied to pose a significant threat with broad potential consequences to public health and safety, agricultural crops and other plants, animals, the environment, materiel, or national security."

The University of Chicago Institutional Oversight of Life Sciences Dual Use Research of Concern (DURC) Policy [1] is based on recommendations and guiding principles from the US Government (*March 2012, DURC Policy,* and *September 2014, Policy for Institutional Oversight of Life Sciences Dual-use Research of Concern)*.

The University of Chicago DURC Policy [2] articulates the practices and procedures required to ensure that DURC is identified at the institutional level and risk mitigation measures are implemented as necessary.

Purpose

The purpose of this policy is to describe and provide guidance for the ongoing institutional review and oversight of certain life sciences research with high-consequence pathogens and toxins in order to identify potential DURC and mitigate risks where appropriate. This policy delineates the roles and responsibilities of the University of Chicago Research Administration (URA), the University of Chicago Principal Investigators (PIs) engaged in research activity that can have DURC potential or that has been identified as DURC, and the University of Chicago DURC Task Force (UC-DTF).

The policy seeks to preserve the benefits of life sciences, while minimizing the risk that the knowledge, information, products, or technologies generated from such research could be used in a manner that results in harm to public health and safety, agricultural crops and other plants, animals, the environment, material, or national security.

Scope of research that requires oversight

Agents and toxins: The 15 agents and toxins listed in this policy are subject to the Select Agent regulations (42 CFR Part 73, 7 CFR Part 331, and 9 CFR Part 121), which set forth the requirements for possession, use, and transfer of select agents and toxins, and have the potential to pose a severe threat to human, animal, or plant health, or to animal or plant products.

Avian influenza virus (highly pathogenic)
Bacillus anthracis
Botulinum neurotoxin[2]
Burkholderia mallei
Burkholderia pseudomallei
Ebola virus
Foot-and-mouth disease virus
Francisella tularensis
Marburg virus
Reconstructed 1918 influenza virus
Rinderpest virus
Toxin-producing strains of *Clostridium botulinum*
Variola major virus
Variola minor virus
Yersinia pestis

Categories of experiments: Planned and ongoing experiments, as well as data obtained from these experiments, should be evaluated for their potential to:

- Enhance the harmful consequences of the agent or toxin
- Disrupt immunity or the effectiveness of an immunization against the agent or toxin without clinical and/or agricultural justification
- Confer to the agent or toxin resistance to clinically and/or agriculturally useful prophylactic or therapeutic interventions against that agent or toxin or facilitates their ability to evade detection methodologies
- Increase the stability, the transmissibility, or the ability to disseminate the agent or toxin
- Alter the host range or tropism of the agent or toxin
- Enhance the susceptibility of a host population to the agent or toxin
- Generate or reconstitute an eradicated or extinct agent or toxin listed above

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[2] For the purposes of this policy, there are no exempt quantities of botulinum neurotoxin. Research involving any quantity of botulinum neurotoxin should be evaluated for DURC potential.

Compliance

As stated in the *September 2014 USG Policy for Institutional Oversight of Life Sciences Dual-use Research of Concern,* non-compliance with this policy may result in suspension, limitation, or termination of US Government (USG) funding, or loss of future USG funding opportunities for the non-compliant USG-funded research project and of USG funds for other life sciences research at the institution, consistent with existing regulations and policies governing USG-funded research, and may subject the University of Chicago to other potential penalties under applicable laws and regulations. The University of Chicago is responsible, in accordance with its relevant statutory and regulatory authorities, for determining how best to ensure compliance with the oversight requirements set forth in the *September 2014 USG Policy* for research it funds. Figure 6 provide a potential workflow to identify, assess, and decide if a proposed experiment can be conducted. DURC issues in life science is a sensitive topic and is addressed with care, e.g. by holding international workshops [2].

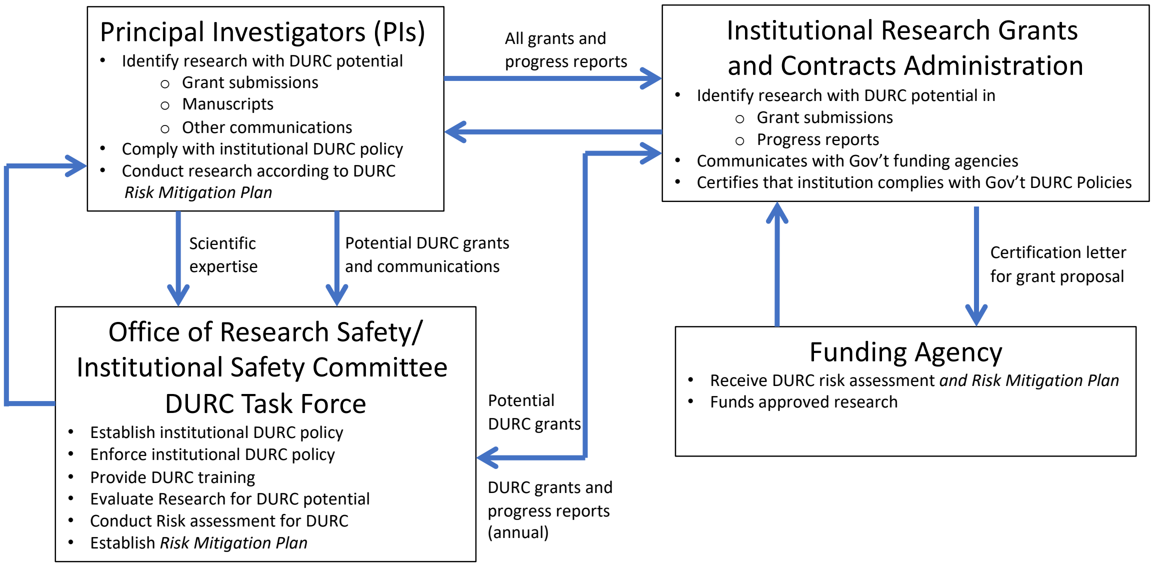

Figure 6: Example of an organizational framework for institutional oversight of DURC

References

[1] National Academies of Sciences, Engineering, and Medicine: *Governance of Dual Use Research in the Life Sciences: Advancing Global Consensus on Research Oversight: Proceedings of a Workshop*, Washington, DC, The National Academies Press (2018) doi:10.17226/25154

[2] University of Chicago Institutional Oversight of Life Sciences Dual Use Research of Concern (DURC) Policy https://researchsafety.uchicago.edu/about/committees/dual-use-research-of-concern-durc-task-force/

Summary of the discussions on transfer into governance, policies, and legal affairs

This part of the expert meeting was devoted to deepen the understanding on the dual-use issues at FELs based on the outcome and technical assessments of the first day of the meeting. The underlying goal was to transfer the ideas and results obtained so far into applicable policies and guidelines by considering aspects of governance and legal affairs. The discussions in this session were centred on the main question of how the associated dual-use risks could be minimized and/or mitigated.

The participants were divided into four parallel working groups, all addressing the same set of key questions. The participants were also asked to differentiate among various stakeholder levels and actors, from individual to community to governmental levels, when findings and recommended actions were formulated.

Findings on an individual level

Key issues that were raised during the discussions focused on research integrity as well as on the necessary awareness about dual use. The main points of the deliberations are summarized in the following sections.

Be responsible

Personal responsibility, integrity, and engagement of the individual scientists were considered to be at the core in order to assess ethical or dual-use risks and to minimize involved risks. Hand in hand with forefront research must be the personal engagement and responsibility of the individual scientists. Community-based codes of conduct provide guidelines and help in that respect and should be followed. Scientists are members of a community, and they carry a collective responsibility for the well-being of their scientific fields. In such, they should watch for the welfare of the community by respecting and enforcing community-based codes of conducts.

Attendees also stated that scientists should not be afraid of standing up to an uncomfortable situation or, if necessary, reporting misuse in an anonymous way given the institutional procedures in such cases. Such action shall be done with care and concern such that the "whistleblowing role" is not used for the wrong reasons. In order to make it possible for scientists to report anonymously and for action to be taken as a result, the institution shall take the responsibility of preparing the appropriate procedures.

Be aware

Participants noted that it is absolutely necessary to raise sensitivity/awareness in staff, evaluation committees, and users about potential dual-use issues. Eventually, dedicated training programmes not only for staff but also for individual researchers proposing experiments should be offered. In that respect, it is critical to fully know the research project (science, techniques, and technology involved) and to shed light on the full scope and consequences in order to understand what aspects might potentially fall under dual-use control or could be of possible concern.

Be open

In collaborative research, it is crucial that the collaboration partners are known. This requires an open dialogue and an active participation in scientific exchange. Scientists have to learn about the others, including, to some extent, their network. The open dialogue and a better knowledge of the network of the users or collaborators will provide a good transparency that is necessary to understand the end goal of a research project.

In that regard, attendees stressed that large research collaborations participating at FEL experiments do not pose a threat, even if scientists from weapon labs are involved, since the collaborating scientists, their affiliations, and their scientific vitae are known. Again, it is important to stress that multiple agencies sponsor basic research, including the military. For these reasons, the experimental content and notation of the type of funding (related to the TRLs) could be noted.

Be curious and stay updated

Moreover, attendees noted that training and education on dual-use issues and on research of concern should be improved. Undergraduate education, for instance, could be complemented by special courses and case studies on science history and science ethics to bring in perspectives and clarity, as well as e.g. holding luncheon seminars quarterly on emerging security and dual-use concerns. They can be recorded and disseminated to the user community.

Findings on an institutional level

Key questions that were addressed in the discussions included the setup of adequate compliance structures at laboratories and in collaboration and partnership agreements. The main points of the discussions are summarized as follows.

Role of the institutions

Institutions are responsible for controlling dual-use technologies. This requires robust compliance structures and guidelines that can withstand government scrutiny. Adequate awareness among staff and users has to be augmented, and the principles and expectations with respect to ethics, transparent behaviour, publications, use of data and technology, and user access regulations have to be clearly articulated. Overall, it is important to demonstrate consistency and clear processes to drive compliance—the more objective, the better. Judgement should be used for process holes. With respect to collaborating partners, the institutional role in guiding collaborations is to affirm ethical principles and imperatives. This implies that the ethics are common and mutually acknowledged. Participants noted that institution-to-institution relationships are better and more effective than peer-to-peer relationships in terms of compliance enforcement.

Develop institutional guidelines

Participants noted that, when setting up special policies and guidelines, the institutions should involve researchers as to ensure that users actively support and abide by the policies. Moreover, policies must be built on higher-level mission statements and on guiding principles that the laboratory may have developed. It is the role of the institutions to create an appropriate "research climate" for that and to communicate the principles to the staff, users, and public. Transparency is best—without it, trust is lost. This includes also the setup of transparent rules regarding collaboration or allowing experiments for researchers funded by military sources (TRL-related funding and intent to publish, see below).

User access and proposal review process

The participants discussed several elements of a potential access policy, and the following points were proposed and raised to support such guidelines: Users (and the institutions) need to disclose the sponsors and the ultimate use of research. Here, it helps if the network of the proposers and the institutions behind them are fully identified. Involved institutions on the proposals must respect intellectual property as stated/requested, for instance in institutional agreements with the host institution. Moreover, declarative statements on proposals to affirm ethical imperatives and civil end use applications are needed.

The proposal review framework should assure that sufficient expertise is available to see "grey areas" and to identify potential dual-use research of concern. Assessing such risks was seen as very important, and special questions and interrogations of the proposal during technical review should be asked. Here, a broad base of understanding is needed to adequately evaluate a proposal for military or economic/industrial application. It is mandatory to raise awareness to the proposal review panel and responsible research facility/beamline managers about risks of dual-use when specific proposals are submitted. For pre-scanning of proposals, computer-aided search for sensitive terms in the proposal could help in that respect. When flagged, the proposer and the institution shall clarify the end goal of the research. Participants pointed out that the samples provided (in accordance to the proposal) should be checked as well. For biological samples, extra care must be taken. List of sensitive samples exists and extensive hands-on experience is readily available in the biological field. Moreover, ideas were also discussed to set a clear technology readiness level (TRL) cut in the research proposed, as defined for example in [1, 2], for which special interviews may have to be conducted to understand its usage.

The discussions also centred on the question of publications. The experts at the meeting agreed that the requirement of the full disclosure of the results was already a very strong measure in support of research integrity, in terms of transparency and communication, and to deter any disguised dual-use research to be conducted. The willingness to publish and to publish data rapidly is already a good sign that no sensitive research that would cause concern will be conducted.

Establish internal compliance structure

The tremendous importance of an organizational unit within a research institution responsible for dual-use issues/compliance was raised many times. Participants agreed that scientists need such points of contact to whom to address any concerns. The institution needs to provide clear procedures, where a case can be raised by submission of a formal complaint, or by request that the designated committee take up a case, in order for the employee to be cleared of charges in the form of circulating rumours. The University of Chicago approach in dealing with DURC that was presented to the audience was seen as a usable model and template from which one can develop. The establishment of such a structure would help to identify specific issues and countermeasures. On an operational level, it could participate in proposals' screening; and the members of this structure could develop focused questions to review in more depth the aim or risk associated with the proposals. Attendees also pointed out that the role of such units can be expanded to include also administrative and legal expertise, e.g. on export control.

It was also recommended to set up an interdisciplinary ethics committee / dual-use review panel at the institution that could be addressed on demand, giving independent advice and guidance. This committee should be summoned in case of questions related to regulating access to facilities in DURC. It is also helpful to proactively think of specific problematic experiments that could come. The recently set up DESY ethics committee that followed the DFG (Deutsche Forschungsgemeinschaft) recommendations about DURC would provide a good example. The UNESCO Recommendation on Science and Scientific Researchers is another source for suggesting a frame for institutional guidelines [3].

Findings on a (scientific) community level

Key questions in the discussions focused on the role of scientific communities and societies and to what extent they are contributing to make research environments more robust against dual-use threats and risks.

Self-regulation of scientific communities and the establishment and maintenance of relations with governmental bodies

The importance of the scientific communities and societies to establish ethical codes and guidelines was strongly emphasized by all participants. Scientific societies can play a major role in developing overall standards and best practices as well as in coordinating efforts among countries and communities. Communities share the responsibility and maintain deep discussions and critical reflections on that. This self-regulating mechanism is inherent to the communities and was considered as very important to mitigate dual-use risks. Scientific societies could also help to raise awareness to new sensitive aspects and issues that pose potential risks and threats and that are not yet on certain dual-use lists. It is the task of the relevant scientific communities to communicate this to government/administration and to establish a protection against any interference against the freedom of science.

In the discussions, it was noted that governmental concerns on dual-use and/or export control should be properly addressed, while recognizing that the scientific community should have its own strong and independent voice. Hence, there was a clear recommendation to pull together as an international scientific community and to leverage scientific societies, national academies, and research institutions in these efforts by establishing and maintaining long-term relations with government bodies and funding agencies. A close dialogue and ability to work with the government is crucial to review procedures and to provide advice to the government on dual-use and/or export control–related goods and technologies.

It is also important e.g. to explain to overseeing bodies that collaboration with dual-purpose labs is not necessarily military-related or even relevant to dual use. Many dual-purpose labs have a strong civilian research branch, and a clear separation between military and civilian research exists. It is crucial that the rules enforcing the separation and the access by civilians, including foreigners, to an infrastructure in such labs are well communicated. This creates trust in receiving users coming from those laboratories that they do not carry military research.

Findings on a governmental level

Key questions that were addressed on that level included the following aspects: Are the national laws and export control regime sufficient/adequate and applicable? How do policy makers and government institutions obtain information/facts from scientific communities? Should governmental institutions limit the academic freedom of individual researchers in order to defend academic freedom in general? What needs to be improved in international control regimes and for the cooperation between countries?

In the discussions, most of the participants stated that existing laws and regulations, e.g. on the export control regime, are adequate and provide a sufficient legislative framework. However, it was noted that regulation and lists cannot capture everything, as they do not keep pace with the rapid development, e.g. in emerging technologies such as artificial intelligence (AI) or with the increasing number of characterized proteins. The regulating authorities are in need of scientific input and should receive reliable information and evidence from scientific societies, national academies, universities, and laboratories. The participants strongly advocated that governmental authorities and scientific communities work together, e.g. by setting up national or international expert committees to clarify existing uncertainties and vague definitions, to develop practical guidelines, and/or to update concrete sensitive item lists.

Participants noted also that clarity in frameworks have to be provided to drive the necessary compliance. In addition to laws and regulations, compliance also requires guidance, which has to be provided through points of contact to support clarification. In that respect, it was noted that the EU guidance for internal export control compliance programmes for academic institutions is planned for the end of 2020. Moreover, several participants reported that Japan is a gold standard in academic compliance.

Reference

[1] HORIZON 2020 – Work Programme 2014–2015: “Technology readiness levels (TRL)”
https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

[2] US Government Accountability Office: “Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects” (2016)
www.gao.gov/assets/680/679006.pdf

[3] “Recommendation on Science and Scientific Researchers”, UNESCO General Conference 2017, ANNEX II and Consolidated report on the implementation by Member States of the 1974 Recommendation on the Status of Scientific Researchers
https://unesdoc.unesco.org/ark:/48223/pf0000259256

Conclusions

FELs and X-ray FELs are important civilian research tools that are now operating in key facilities around the world. Their basic science, complexity, and costs make them ideal for international cooperation. Later military applications cannot be ruled out. The current political climate makes scientific cooperation more difficult (visa denial or delay, blocking projects or conference visits, exchange of scholars, etc.). However, science is mainly an international enterprise, and big advancements are made by pooling the efforts of the scientific communities. Science for the future also faces new risks and challenges that can be solved only by common efforts. The talks of the expert meeting observed that the success of the scientific enterprise of any nation requires maintaining a balance between open collaboration and secure competition. Ethical, legal, and scientific guidelines must be established by responsible institutions and entities as a framework to prevent misuse or to discuss conflicting objectives. Commonly agreed “codes of conduct” are creating a standard basis for discussion and awareness. Some countries are convening experts and stakeholders in round-table discussions or establishing study groups to assess risks, identify benefits, and examine policy responses of FEL science. Others are calling for closer cooperation or developing guidelines of criteria for responsible behaviour in international cooperation.

That said, some of the most important results obtained in regards to science and technology related to FEL stated that:

1. FELs in general will play *no* role for the foreseeable future in the development of directed-energy weapons (DEWs).
2. The only known and potentially viable path for laser enrichment of uranium requires accurately tuned light at longer wavelengths (visible or IR) and not X-rays from X-ray FELs. The associated proliferation risk for X-ray FEL technology is small.
3. X-ray technologies, including the superconducting technologies to accelerate electrons to very high energies, were not considered directly critical. However, the relevance of X-rays for dual-use applications remains a general concern. Export control mechanisms are considered sufficient to deal with the dual-use problem for these technology developments.

As DESY and European XFEL are bound by German law, it is necessary to remind that research in Germany benefits from the German Basic Law guaranteeing academic freedom. Nevertheless, with this freedom comes great responsibility.

In order to ensure as much as possible that no dual-use research is conducted and to avoid the misuse of research in the premises of European XFEL and DESY, the following recommendations were issued:

1. Commit to publishing data, and do so rapidly—minimizing the embargo period. Willingness to publish is a good sign that no military-related research will be conducted.
2. Publish short and simple user rules to ensure proper compliance to legal constraints (export control, etc.).
3. Raise the awareness of (educate) staff members, primary investigators, and review panels on the dual-use issue.
4. Provide adequate security to researcher’s assets (data, etc.).
5. Keep close contact with authorities to comply with regulations (export control, list of sensitive samples, etc.).
6. Necessary but not so easy to implement is building knowledge in house on dual-use issues in order to be able to check problematic science cases proposed by researchers, e.g. by recruiting expertise, or by requesting this expertise from governmental bodies; hence, stressing Point 5.

It was noted that access by external or internal users to facility capabilities is controlled through the proposal review process or an internal process that vets the scientific proposal in terms of quality but also raises a flag if in doubt regarding potential dual use. However, research conducted by users who pay for accessing the facility, and this includes beamtime, in accordance with European XFEL’s policies for commercial use of the facility, would not be addressed by such a process since these experiments would not undergo proposal review by the European XFEL proposal review panel. Commercial use of the facility was not covered during the workshop, in part due to the fact that such access accounts for a small fraction of the usage of the facility resources. Such an access mode is exempt from publication (data, patent, or in a scientific journal or public repository). Nevertheless, the scientific or engineering cases addressed will have to be reviewed under the seal of confidentiality by people entrusted by the institutions.

To reach the goal set at the start of this workshop, the policies to come dealing with dual-use research of concern at an X-ray FEL will be inspired by existing policies in other fields of science and by the findings summarized in this manuscript. That said, some words of caution regarding reliance on policies, knowledge, and doing one’s personal best: We need to remind ourselves that, no matter what rules and safeguards are set up in order to avoid dual-use research at facilities, such as the European XFEL, one has to simply accept that some research will end up being carried out that might have military relevance. However, the rules put in place will deter the grossest attempts. Finally, those policies shall look beyond those findings and be general enough to cover the new scientific and engineering topics to come.

Acknowledgements

DESY and European XFEL organizers are truly indebted to the incredible commitment of all the participants. The editors would like to acknowledge the support by the DESY and European XFEL colleagues in the drafting of the report. The editors also would like to extend their special thanks to the colleagues that have authoring or co-authoring some of the above sections, in particular J. Bagger, S. Biedron, J. Kanabrocki, E.M. Campbell, M. Ferrario, H.-A. Eckel, D. Wang, W. Fuss, and R. Snyder.

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Extended bibliography

- Usage and Development of Free-Electron Lasers (Historical Review)
  - Tenth International Free Electron Laser Conference, 1989
    https://apps.dtic.mil/dtic/tr/fulltext/u2/a207016.pdf
  - Boeing to Develop Free Electron Laser for US Navy (2009)
    https://newatlas.com/boeing-us-navy-contract-free-electron-laser/11480/
  - Boeing Announces Projection of 1st Photoelectron Beam from Navy's Superconducting Injector (2010)
    https://boeing.mediaroom.com/2010-07-16-Boeing-Announces-Projection-of-1st-Photoelectron-Beam-from-Navys-Superconducting-Injector
  - Y. Socol: "High-Power Free-Electron Lasers – Technology and Future Applications", *Opt. Las. Tech*, **2013**
    https://doi.org/10.1016/j.optlastec.2012.06.040
  - C Pellegrini: "X-ray free-electron lasers: from dreams to reality", *Phys. Scr.* **2016** 014004 (2016)
  - China's Progress with Directed Energy Weapons (2017)
    https://www.uscc.gov/sites/default/files/Fisher_Combined.pdf
  - China Develops World's Brightest VUV Free Electron Laser Research Facility (2017)
    http://english.cas.cn/head/201701/t20170112_173367.shtml
- Reading the open literature in accelerator and FEL technologies also helps one find and understand the potential sensitivities:
  - National Research Council: "Scientific Assessment of High-Power Free-Electron Laser Technology", Washington, DC, The National Academies Press (2009) https://doi.org/10.17226/12484.
  - Congressional Report—Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress (2015)
    https://fas.org/sgp/crs/weapons/R41526.pdf
  - United Nations Office for Disarmament Affairs (UNODA)
    https://www.un.org/disarmament/about/

The assessment of the "readiness" of a technology through the definitions of technology readiness levels can prove to be useful in the assessment of the *Technology Readiness Assessment Guide (2016)*: www.gao.gov/assets/680/679006.pdf

Examples of other user policies include that of:

- 2005–2014: 10 years of LIL/ILP open campaign
  www-lmj.cea.fr/docs/2015/ILP_VERSION_WEB.pdf
- CEA-DAM – *User Guide LMJ-PETAL (2017)*
  http://www-lmj.cea.fr//docs//2017//LMJ_PETAL_Users_guide_v1.3.pdf
- Orion - Atomic Weapons Establishment (AWE) – Academic Access
  https://www.clf.stfc.ac.uk/Pages/Academic-Access-to-Orion.aspx
- Biosecurity and Dual-Use Research in the Life Sciences:
  - *Biotechnology Research in an Age of Terrorism* (2004)
    ISBN-13: 978-0-309-08977-7
    https://doi.org/10.17226/10827
  - *Science and Security in a Post 9/11 World: A Report Based on Regional Discussions Between the Science and Security Communities* (2007)
    ISBN-13: 978-0-309-11191-1
    https://www.ncbi.nlm.nih.gov/books/NBK11496/
  - "Governing 'dual-use' research in Canada: A policy review", Science and Public Policy, **41** (1), 76–93 (2014)
    doi:10.1093/scipol/sct038
  - UKRI, Medical Research Council: "Managing risks of research misuse" (2015)
    https://mrc.ukri.org/research/policies-and-guidance-for-researchers/managing-risks-of-research-misuse/
  - National Academies of Sciences, Engineering, and Medicine: "Governance of Dual Use Research in the Life Sciences: Advancing Global Consensus on Research Oversight", Advancing Global Consensus on Research Oversight: Proceedings of a Workshop (2018)
    doi:10.17226/25154
  - IAP, Science Health Policy: "Assessing the Potential Biosecurity Risks and Benefits of Advances in Science and Technology" (2019)
    https://www.interacademies.org/node/51554
- Ethics and Policies in Artificial Intelligence (AI):
  - The US cryptography policies can also be useful in providing knowledge and examples. For instance, a 1996 report from the US National Research Council,

“Cryptography's Role in Securing the Information Society.” Washington, DC, The National Academies Press, doi:10.17226/5131 and references therein.

  - IEEE: “Ethically Aligned Design” (2016)
    https://ethicsinaction.ieee.org/#set-the-standard
  - Global Council on Extended Intelligence
    https://globalcxi.org
  - Open Community for Ethics in Autonomous and Intelligent Systems (OCEANIS)
    https://ethicsstandards.org

- Multilateral Non-Proliferation, Export Control Regimes
  - Understanding Non-proliferation related to “dirty bombs”
    https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-dirty-bombs.html
  - Missile Technology Control Regime
    https://mtcr.info
  - The Australia Group
    https://australiagroup.net/en
  - THE WASSENAAR ARRANGEMENT On Export Controls for Conventional Arms and Dual-Use Goods and Technologies
    https://www.wassenaar.org
  - Nuclear Suppliers Group
    https://www.nuclearsuppliersgroup.org/en
  - Zangger Committee
    http://www.zanggercommittee.org
  - Common Dual-Use and Military Control Lists of the EU
    https://2009-2017.state.gov/strategictrade/resources/controllist/index.htm
  - US Export Controls (Summary of all links for the US Departments of State, Commerce, Homeland Security, Treasury, Defence, and Energy)
    https://2009-2017.state.gov/strategictrade/resources/c43182.htm
  - Non-governmental organizations that have additional guidance points
    https://2009-2017.state.gov/strategictrade/resources/c43116.htm

- Further Reading
  - Good Research Practice: Guidelines for Safeguarding Good Research Practice
    https://www.dfg.de/en/research_funding/principles_dfg_funding/good_scientific_practice/
  - Scientific Freedom and Scientific Responsibility (2014)
    https://www.leopoldina.org/en/publications/detailview/publication/wissenschaftsfreiheit-und-wissenschaftsverantwortung-2014/
  - Research focusing exclusively on civil applications (2015)
    https://ec.europa.eu/research/participants/data/ref/h2020/other/hi/guide_research-civil-apps_en.pdf
  - Doing Global Science: A Guide to Responsible Conduct in the Global Research Enterprise (2016)
    ISBN:9780691170756 / https://www.interacademies.org/node/49398
  - Guidelines for researchers on dual use and misuse of research (2017)
    https://www.uhasselt.be/documents/DOC/2017VLIR003_FolderOnderzoek_EN_DEF_20180212.pdf
  - Guidance: How to complete your ethics self-assessment (2019)
    https://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/ethics/h2020_hi_ethics-self-assess_en.pdf
  - Guidelines to counter foreign interference in the Australian university sector (2019)
    https://www.education.gov.au/news/guidelines-counter-foreign-interference-australian-university-sector-released
  - Export Controls: State and Commerce Should Improve Guidance and Outreach to Address University-Specific Compliance Issues (2020)
    https://www.gao.gov/assets/710/706829.pdf

International Expert Meeting Agenda

Use of free-electron lasers and beyond: Scientific, technological, and legal aspects of dual use in international scientific cooperation

4–5 November 2019 at DESY Hamburg, Germany – FLASH Seminar Room

https://indico.desy.de/indico/event/24293

Overall goal of the meeting

Ensure to safeguard open international scientific collaboration around FELs

Objectives of the meeting

- Identify and assess potential dual use issues in FEL-related S&T areas—organized in four topics
- Discuss and exchange best practices on dual use awareness, control, and governance
- Explore principles and practices to minimize dual-use risks and concerns in international collaboration
- Contribute to an international and forward-looking dialogue in times of global tension

Agenda

Monday, 4 November 2019:

10:00–13:00: Opening plenary (FLASH Seminar Room)

- **Welcome and introduction**
  Helmut Dosch, DESY, and Robert Feidenhans'l, European XFEL (2 x 10')
    - Goals of the meeting and key questions to address
    - "A pedestrian's guide to FEL"

- **Balancing open science collaboration and national security (Chair: R. Feidenhans'l)**
  Overview of talks setting the context:
    - Lessons learned from history and current challenges (20')
      Götz Neuneck, former Co-Director, Institute for Peace Research and Security Policy IFSH and Pugwash Germany, Hamburg/GER

- Is international cooperation under pressure—current challenges and barriers in the scientific realm—with four perspectives from speakers from the USA, Russia, China, and the EU (4 x 15’ + 4 x 5’ discussions)

    - Roger Falcone, Past President, APS and UC Berkeley, USA
    - Boris Sharkov, Vice Director, JINR Dubna, RUS
    - Zhiyuan Zhu, Vice President, ShanghaiTech University, CAS, China
    - Roland Sauerbrey, Director, Helmholtz-Zentrum Dresden-Rossendorf

- Dual use and export control systems: Balancing national security and academic freedom (20’)
  Jonathan Bagger, Director, TRIUMF, Canada

- How to do collaborative, international accelerator-based science while still protecting one’s self (20’)
  Sandra Biedron, Element Aero, USA

13:00 –14:00: Break

14:00–16:30: Parallel sessions: Scientific/technical issues–Relevance and application (150’)

Key questions:

- *Can we identify potential dual-use issues in the FEL science and technology (S&T) area? To what extent and under what circumstances are FELs and/or FEL technologies relevant (and sensitive) for security and for military-related applications?*

- *Can we assess the seriousness and consequences of the considered cases in terms of proliferation, stability and/or even weaponization risks?*

- *What are ways to mitigate or minimize dual-use risks or to limit proliferation risks for harmful applications by adversarial state or non-state actors? Do we need to put certain areas of FEL S&T under stricter control and which areas have to be considered?*

Parallel Session A: FELs as energy-directed weapons (Bldg. 49a, Room 204)

- Chair: Mike E. Campbell (U Rochester)
- Key note: Hans-Albert Eckel (DLR)
- Further contributions by other participants

Parallel Session B: SRF accelerator and photon system technology (Bldg. 28k, Room O2.010)

- Chair: Tetsuya Ishikawa (SPring-8)
- Key note: Hans Weise (DESY)
- Further contributions by Dong Wang (SARI) and other participants

Parallel Session C: FELs and isotope separation (Bldg. 46g, Room O1.031)

- Chair: Robert Rosner (U Chicago)
- Key note: Werner Fuss (Max Planck Institute of Quantum Optics, MPQ)
- Further contributions by Ryan Snyder (IFSH), Evgeni Chesnokov (Voevodsky Institute), and other participants

Parallel Session D: FEL science: Materials under extreme conditions and other science (FLASH Seminar Room)

- Chair: Michele Svandrlik (ELETTRA / FELs of Europe)
- Key notes: John L. Sarrao (LANL)
- Further contributions by Tom Cowan (HZDR), and other participants

16:30–17:00: Break

17:00–19:00: Plenaries (Chair: Helmut Dosch, DESY)

Summaries from parallel sessions
Summary reports from the parallel sessions will be 10’ each +5’ questions

Discussions
Open Discussion incl. wrap-up of the first day and preparation on topics for day 2 (45’)

Tuesday, 5 November 2019

09:00: Plenary (Chair: Robert Feidenhans'l, European XFEL) – FLASH Seminar room

Keynote:
Dual Use Research of Concern in Life Sciences (20') – Joseph Kanabrocki, U Chicago

Reminder of the results of Day 1 and organization of four parallel sessions—with the aim of looking into aspects of ethics, dual use policies, export control, security and safety, arms control, and legislation

Parallel sessions: Transfer into governance, policies, and legal Affairs (100')
(Four parallel sessions with chairs: Gerald Epstein, Jeff Smith, Giovanni Anelli, and Stefan Müller)

Key questions and approaches to be discussed by all groups:

- *What can be done on an individual level?*
  How to make sure that ethical aspects in FEL S&T are properly addressed and assessed?
  How to raise awareness and improve training and education on dual-use issues and on research of concern?

- *What can be done on an institutional level?*
  How to set up and enforce compliance and governance at laboratories and in collaboration and partnership agreements? Should research institutions regulate cooperation with individual researchers, institutions, or even countries that do not adhere to the values of academic freedom and good scientific practice and that do not openly display a separation of civil and military research? How should access to FEL facilities be regulated if there are dual-use concerns?

- *What can be done on a (science) community level?*
  How can science communities better identify and address sensitive issues at FELs. What is necessary to make the open access / peer review systems and publication systems a self-protective and self-regulating environment that is robust against dual use and misuse? What codes and policies need to be developed by science societies, associations, and organizations?

- *What can be done on a governmental level?*
  Are national laws and export control regimes sufficient/adequate and applicable? How do policy makers and government institutions obtain information/facts from scientific communities? Should governmental institutions limit the academic freedom of individual researchers in order to defend academic freedom in general? What needs to be improved in international control regimes and for the cooperation between countries?

11:00–11:30: Break

11:30–12:30: Summaries from parallel sessions (Chair: Christian Harringa)
Summary reports from the parallel sessions should be 10’ each +5’ questions

12:30–13:30: Open discussions and conclusions from the meeting (60’)
(Chairs: Helmut Dosch, Robert Feidenhans’l)

List of participants

Country	Institute	Last name	First name
AT	International Atomic Energy Agency (IAEA)	Smith	Jeff
CA	TRIUMF	Bagger	Jonathan
CH	European Organization for Nuclear Research (CERN)	Anelli	Giovanni
	Paul Scherrer Institute (PSI) – SwissFEL	Müller	Stefan
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		Felkers	Björn
		Graafsma	Heinz
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		Lehner	Frank
		Maier	Andreas
		Ploenjes-Palm	Elke
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		Weckert	Edgar
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	Universität Hamburg	Himmel	Mirko
		Jeremias	Gunnar
		Kirchner	Gerald
FR	Polytechnique/CNRS	Audebert	Patrick
IT	FELs of Europe	Svandrlik	Michele
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	University of Bologna	Boscherini	Federico
JP	High Energy Accelerator Research Organization (KEK)	Okada	Yasuhiro
	SPring-8 Angstrom Compact free electron LAser (SACLA)	Ishikawa	Tetsuya
RU	Budker Institute of Nuclear Physics (BINP)	Kulipanov	Gennady
	Joint Institute for Nuclear Research (JINR) Dubna	Sharkov	Boris
	Lebedev Institute RAS	Ionin	Andrey
	National Research Centre (NRC “Kurchatov Institute”)	Blagov	Alexander
		Kravchuk	Vladimir
		Rychev	Mikhail
	Voevodsky Institute	Chesnokov	Evgeniy
UK	Atomic Weapons Establishment (AWE)	Randewich	Andrew
USA	Center for the Study of Weapons of Mass Destruction at the National Defense University	Epstein	Gerald
	Element Aero	Biedron	Sandra
	Facility for Rare Isotope Beams (FRIB) National Superconducting Cyclotron Laboratory (NSCL)	Glasmacher	Thomas
	Thomas Jefferson National Accelerator Facility (Jefferson Lab)	Henderson	Stuart
	Los Alamos National Lab (LANL)	Sarrao	John
	Lawrence Livermore National Laboratory (LLNL) / University of Rochester	Campbell	E. Michael
	University of Chicago	Kanabrocki	Joseph
		Rosner	Robert
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