REPORT

Workshop on Nuclear Energy Beyond Electricity

Sponsored by

The Infrastructure Development Working Group (IDWG)

Alex Burkart and Zbigniew Kubacki, Co-chairs

24 September 2019

Ministry of Energy
Warsaw, Poland

IFNEC
INTERNATIONAL FRAMEWORK FOR NUCLEAR ENERGY COOPERATION

THE INTERNATIONAL FRAMEWORK FOR NUCLEAR ENERGY COOPERATION

The International Framework for Nuclear Energy Cooperation provides a forum for cooperation among participating states to explore mutually beneficial approaches to ensure the use of nuclear energy for peaceful purposes proceeds in a manner that is efficient and meets the highest standards of safety, security and non-proliferation.

The 34 IFNEC member countries are: Argentina, Armenia, Australia, Bahrain, Bulgaria, Canada, China, Estonia, France, Germany, Ghana, Hungary, Italy, Japan, Jordan, Kazakhstan, Kenya, Korea, Kuwait, Lithuania, Morocco, the Netherlands, Niger, Oman, Poland, Romania, Russia, Senegal, Sierra Leone, Slovenia, Ukraine, the United Arab Emirates, the United Kingdom and the United States.

The 31 Observer countries are: Algeria, Bangladesh, Belgium, Brazil, Chile, the Czech Republic, Egypt, Finland, Georgia, Greece, Indonesia, Latvia, Malaysia, Mexico, Moldova, Mongolia, Nigeria, Philippines, Qatar, Saudi Arabia, Singapore, Slovak Republic, South Africa, Spain, Sweden, Switzerland, Tanzania, Tunisia, Turkey, Uganda and Vietnam.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 34 countries: Argentina, Australia, Austria, Belgium, Bulgaria, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Korea, Romania, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

The Nuclear Energy Agency serves as technical secretariat to IFNEC.

The Infrastructure Development Working Group

Co-chairs

- *Alex Burkart* of the US Department of State
- *Zbigniew Kubacki* of the Ministry of Energy of Poland

The Infrastructure Development Working Group (IDWG) was established to identify areas of global infrastructure that could be improved through international cooperation in order to support the development of the physical, organisational and legislative infrastructure needed to ensure that the use of nuclear energy for peaceful purposes proceeds in a manner that is efficient and meets the highest standards of safety, security and non-proliferation.

Scope

- Human Resource Development
- Radioactive Waste Management, Including Infrastructure Issues for a Multinational Spent Fuel Repository
- Small Modular Reactors
- Stakeholder Involvement and Public Acceptance
- Nuclear Safety
- Nuclear Security
- Emergency Preparedness and Response

Activities and output

The IDWG carries out its work through the organisation of regular WG meetings, specific workshops and conferences focused on sharing of “best practices” in the areas within its scope. The output is in the form of presentations from experts, summary reports to the Steering Group, and whenever possible, publications of reports – all available in the Resource Library.

All the presentations from the workshop can be downloaded from the IFNEC website: www.ifnec.org/ifnec/jcms/g_12595/idwg-workshop-nuclear-energy-beyond-electricity.

Foreword

The Infrastructure Development Working Group (IDWG) supports the development of the infrastructure needed to ensure that the use of nuclear energy for peaceful purposes proceeds in a manner that is efficient and meets the highest standards of safety, security and non-proliferation. Particular areas of emphasis include human resource development, radioactive waste management, small modular reactors, nuclear safety and regulation, nuclear security and emergency preparedness and response.

The topic of this IDWG workshop was “nuclear beyond electricity”. Nuclear technology is today widely used to produce electricity without a negative impact on the environment. No harmful emissions, the small footprints of nuclear power plants and the relatively small amount of waste are some of the key features of nuclear technology. However, electricity accounts for only 18% of the energy used worldwide. The rest is mostly heat generation and transport, which are today almost entirely produced by high emission sources.

Industrial heat production, district heating by cogeneration of electricity and heat, hydrogen and synthetic fuels for transport could and should be the new territory conquered by nuclear energy, especially with a view to help decarbonize those sectors. The IDWG workshop discussed the broad topics of non-electric applications of nuclear energy, and then addressed the key role that High Temperature Reactors (HTRs) could play to provide both electricity and process heat applications. The last session of the workshop focused on the role of hydrogen, one of the most promising low carbon energy vectors – which can be produced thanks to nuclear energy, and in particular from HTRs, and discussed other innovations such as micro-reactors.

Workshop participants were also invited to visit the National Centre for Nuclear Research (NCBJ), involved in development of High Temperature Gas-cooled Reactors. The portfolio of NCBJ is wide, spanning from basic research in physics, through applied research on materials, detectors and accelerators, up to commercial production of radioisotopes and particle accelerator for science, medicine and industry (more details are included in this program).

Alex Burkart and Zbigniew Kubacki,
IDWG Co-chairs NEA and IAEA

AGENDA

24 September 2019

8:00-9:00	**Registration and welcome coffee**
9:00-9:20	**Welcome IDWG Co-Chairs: Alex Burkart and Zbigniew Kubacki**
9:30-10:45	**Non-electric applications of nuclear energy – Economic and environmental**
9:30-9:50	**Environmental aspects of energy production and cogeneration** Institute of Nuclear Chemistry and Technology, Poland – Andrzej G. Chmielewski, Director
9:50-10:10	**Role of nuclear cogeneration in a low carbon energy future** OECD Nuclear Energy Agency – Henri Paillère, Deputy Head Division of Nuclear Technology Development and Economics
10:10-10:30	**IAEA Activities on Non-electric Applications of Nuclear Energy** International Atomic Energy Agency – Ibrahim KHAMIS, Senior Nuclear Engineer, Project Manager for Non-Electric Applications of Nuclear Power
10:30-10:45	**Q&A**
11:00-12:15	**High Temperature Reactors – Beyond electricity generation**
11:00-11:25	**Very High Temperature Reactor, a Gen IV system** Gen IV International Forum VHTR system steering committee – Li Fu
11:25-11:50	**Scientific project for HTR in Poland** NCBJ – Deputy Director for Innovation and Commercialization – Paweł SOBKOWICZ
11:50-12:15	**Chinese HTR program** Tsinghua University – Deputy Chief Engineer, Institute of Nuclear and New Energy Technology (INET) – Li Fu
12:15-12:40	**Russian HTR program** State Atomic Energy Corporation “Rosatom” – Vladimir Artisiuk, Councilor, Advisor to Director General
12:40-13:05	**Japanese HTGR development program** Japan Atomic Energy Agency (JAEA) – Taiju SHIBATA, Leader, International Cooperation Group
13:05-13:15	**Q&A**

14:30-17:30	**Future role of Hydrogen and development of innovative nuclear systems**
14:30-15:00	**The Future of Hydrogen** International Energy Agency – Uwe REMME, Energy Modeller
15:00-15:20	**Nuclear production of hydrogen** Japan Atomic Energy Agency – Xing L. YAN, Deputy Director of Reactor Systems Design Department
15:20-15:40	**Micro-reactors for special applications and fuel cycle** URENCO Limited – Chris WHITE, Director, Government Affairs
15:40-16:30	**Micro Modular Reactor** Ultra Safe Nuclear Corporation – Francesco VENNERI, Chief Executive Officer
16:30-16:50	**Nuclear Innovation 2050: HTGR cogeneration** National Centre for Nuclear Research – Grzegorz WROCHNA, International Cooperation Manager
16:50-17:15	**Q&A**
17:15-17:25	**Summary of discussions** IFNEC Technical Secretariat
17:25-17:30	**Closing remarks from the Co-Chairs**

SESSION 1

Non-electric applications of nuclear energy – Economic and environmental

This session included three presentations summarized below

A. Environmental aspects of energy production and cogeneration

Institute of Nuclear Chemistry and Technology, Poland – Andrzej G. Chmielewski, Director

Mr Chmielewski provided an overview of the importance of the atmosphere, how human action is affecting nature and its effects. Among the most salient reasons of such effects are:

- growth in population, distribution across the world, concentration in cities;
- increased energy needs and per capita use;
- use of fossil fuels and their effects in the environment and health – such as premature deaths.

Unfortunately coal and fossil fuels represent up to 40 to 50% of the energy sources, and there are also the emissions of different pollutants to take into account - not only greenhouse effects but also other types of pollutants, and this brings other health problems such as prematurely shortening life span .

As countries recognize these effects, many (such as Finland and France) have decided to phase out of coal entirely. The ways in which to achieve this are different in each country. Germany's case was presented as an example of a country that has decided to transform its whole energy mix to renewables; however, this might not be enough – Germany currently has more installed capacity than the energy that can actually be produced.

Another good example of transitions to cleaner mixes is the use of electric cars, which are viewed as a solution – but where is the energy they require coming from? If they are being charged by coal plants, then this is not the solution either.

He considered that the problem today is the amount of news that comes from the Internet, much of which is fake news. Another problem is ignorance, lack of education.

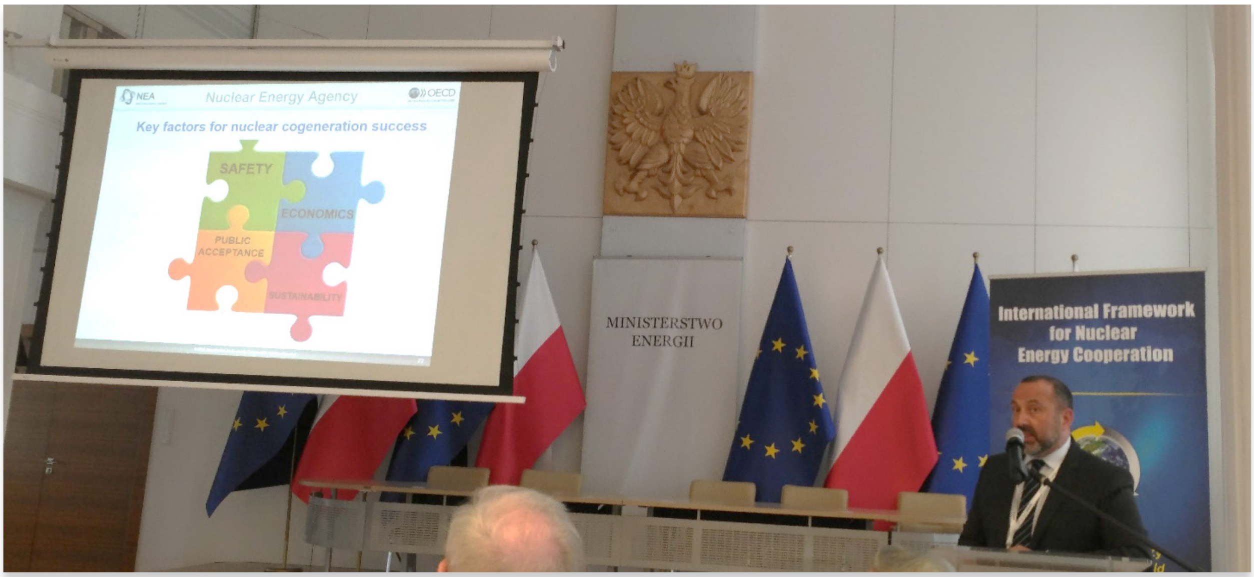
Mr Chmielewski then made a detailed overview of the non-electric applications nuclear energy currently has, concluding that nuclear non-electric applications save lives with over 40 million different medical procedures done with nuclear methods. And while these practices are recognized and accepted all over the world, nuclear electricity production doesn't enjoy the same acceptance.

His final message is that "nuclear energy and its non-power applications are key 21st century technologies to protect human health and the environment."

There was particular interest about who can take part of the program and the benefits that the Multinational Design Evaluation Programme (MDEP) represents for the industry in its communication with the regulators.

B. Role of nuclear cogeneration in a low carbon energy future

OECD Nuclear Energy Agency – Henri Paillère, Deputy Head Division of Nuclear Technology Development and Economics



Mr Paillère provided an overview of the current CO_2 emissions per fuel and sector, and gave more details in the electricity mix highlighting its main trends worldwide. Below are the main takeaways:

- Industry remains the main CO_2 emitter.
- Although there is progress being made, still 2/3 of electricity comes from coal sources.
- Nuclear is the lowest CO_2 emitter source but its share has been going down in the last few years.
- Even if countries build a lot of renewables, there is still a long way to go to reach the goals established.

The point is that very often we see that policies aiming at promoting renewables will fail if there is not a strategy to get rid of the fossil fuels. CO_2 is not the only problem we have, we have a problem with air pollution and all the health issues this brings. And this should be a short-term driver to encourage cleaner energies and cleaner air in the cities.

There are very few support mechanisms for nuclear, there are laws being passed or prepared to exclude nuclear from financing mechanisms. Nuclear has been historically a low-carbon energy and has been used to decarbonize the systems – as France and Sweden have done several years ago.

Most of the reactors today are used to produce electricity. There are few district heating, but most is for electricity. GEN IV with its work in the VHTR – the first stage is in temperatures of 700°C.

We see an interest in SMR in GEN IV SMR and early deployment might be possible if they address real market needs – such as hydrogen production.

Challenges for nuclear new build of Gen III and Gen III+:

- Investment costs are very high.
- Construction time is longer than other alternatives.
- Public acceptance is key.

However, developing non-electric applications might address some of these. For example, in current nuclear reactors, 2/3 of the heat is wasted, developing non-electric applications this heat could be used.

Key nuclear factors:

- Economics – get the end user to invest.
- Public acceptance – talking about the benefits of nuclear cogeneration will be very important to address this concern. It is our responsibility to help explain all that this can do.
- Sustainability – we need to have a recognition that nuclear can contribute to the system.

Q&A session:

- There are agencies and organizations that play an important role such as the climate strike; very soon we will have a huge movement of young people. Does the NEA provide them with knowledge?
- Mr Paillère replied that agencies (such as the NEA) are aware of the need to bring young people in the field. However, the outreach has to be done carefully since being an intergovernmental organization it can be viewed as promoting nuclear energy and this is not the mission of the NEA. We need other organizations (NGOs or the IEA) to spread the word. If it is just the nuclear organizations talking, we will fail because we do not have enough outreach. Luckily, there are more organizations each day and this is a good sign.
- There is a quite known process in the E.U. about the sustainable financing and here nuclear power is treated as non-sustainable and this is the key for Gen IV and for deploying in the future. Is there a place or a time for the NEA to express its concern that treating nuclear power as a non-sustainable source makes things worse in the sense of allowing it to develop?
- Mr Paillère indicated that there is concern, but it is very difficult to take a position. Individual member countries are more active than we are globally. However, the NEA does recognize the risk that if this carries on it will be detrimental to the nuclear sector. We are in a difficult political situation responding to this. The only thing we can do is provide as many facts as possible. One of the issues raised was the management of waste, and we have a clear message at the NEA about this, maybe we need to repeat this kind of messages in a clearer way.
- The key to public acceptance is communication and one of the things we forget is listening as well as speaking. Who aren't we listening to?
- Mr Paillère replied that we are not listening enough the worries of the younger generation; some might be ill founded so we need to have more dialogue with them. For too long the industry has neglected that part of society and we are talking about nuclear for the next 40 years, so we need to talk to them.

C. IAEA Activities on Non-electric Applications of Nuclear Energy

International Atomic Energy Agency – Ibrahim Khamis, Senior Nuclear Engineer, Project Manager for Non-Electric Applications of Nuclear Power

Mr Khamis provided an introduction to nuclear reactors, research reactors and also nuclear power reactors which have non-electric applications. He highlighted that for power reactors it has already been proven that they can be used for other applications:

- Nuclear can produce electricity.
- Nuclear can be used for district heating.
- Nuclear can produce hydrogen.
- Nuclear power can desalinate.
- Nuclear power produces Cobalt 60 and radioisotopes.

However, nuclear has to optimize cogeneration for the future of nuclear energy. This will also help if nuclear wants to compete with other sources of energy in terms of costs and efficiency.

So the question is how do we make a case for the current reactors? Hydrogen production, for example, and even at competitive prices. We should consider the waste heat that NPPs produce, if we could use only 25% of it, we could reduce the CO_2 emissions even more.

We need to make sure that decision makers are aware and well informed of this.

The challenges are:

- Public acceptance.
- How to attract the industry, which needs fast solutions and "not in my backyard". It is important to recognize the different industry needs.
- Economics – we are addressing licensability and working on different approaches to address this, but this is not easy because of the different regulations in each country.

The IAEA contributes through publications, events, technical meetings, information exchanges.

Q&A session:

- We know that public support is crucial for new build, should cogeneration be regarded as low cost heating resource as a long-term public relation measure or as a very important revenue for construction planning?
- Mr Khamis replied that it is a matter of both. First of all, we have to think about as a good case to make nuclear more favorable for the public, as when you produce something for free or at a

very low price. When it comes to investment, it is a financing equation, but when it comes to operation it is a matter of public acceptance.

- We are mixing two “regimes”: information and emotions, and a lot of opposition is based on emotions and not in information; and information doesn’t work on emotions. We should look at the anti-vaccination movement for example. So what we should do is we should appeal to those things just mentioned, things that create positive emotions and this shouldn’t be trough showing reports to the young generation on the streets. We need to have different messages to build up public support. What and how can we do it?
- Mr Khamis indicated that the IAEA has young students who are working on these things and the tool is what sometimes attracts them to the business. At the IAEA they have a lot of visitors who see the agency as a whole, to educate them on what are the advanced technologies and things the agency does.
- We know that reactors operate at high pressure and these tools use the conventional numbers just because they were optimized, but we could optimize them to work at other levels. Is there a program to involve NPP operators to optimize this?
- Mr Khamis replied that they are focusing and trying to persuade on how to extract steam from the turbine. So, it’s not the reactor itself. Additional business could be done with it. The idea is to use what is being “wasted” from the operating reactors. However, the IAEA cannot go to the vendors and ask them to change their current reactors. Hence, the focus is not on changing the reactor itself for the current reactors, but for future reactors.

SESSION 2

High Temperature Reactors – Beyond electricity generation

This session included five presentations summarized below

D. Very High Temperature Reactor, a Gen IV System

Gen IV International Forum VHTR system steering committee – Li Fu

Mr Fu provided a brief on the Generation IV International Forum goals, organization and activities:

- Identify potential areas of multilateral collaborations on Generation IV nuclear energy systems.
- Foster collaborative R&D projects.
- Establish guidelines for the collaborations and reporting of their results.
- Regularly review the progress and make recommendations on the direction of collaborative R&D projects.

He then focused on the activities related to the Very High Temperature Reactor (VHTR), its characteristics, goals and projects:

- Materials (MAT);
- Fuel and Fuel Cycle (FFC);
- Hydrogen Production (H.P.);
- Computational Methods, Validation & Benchmarking (CMVB).

The VHTR System Arrangement has nine signatories: Australia, China, Canada, Euratom, France, Japan, Korea, United Kingdom, United States.

The future activities of the group will be targeted towards medium-term demonstration, market adaptation and long-term performance/flexibility optimization.

Prospects for VHTR:

- It is excellent for electricity generation with higher efficiency.
- It is excellent for a wide range of process heat applications.
  - With steam, there is a large market.
  - With helium, for hydrogen production.
- The site can be close to the end user because of its safety features.
- It has deployment flexibility.
- It has product flexibility.
- It poses cost reduction opportunities.

Readiness of the VHTR:

- There are many designs available worldwide.
- Process heat technology has been proven.
- HTR-PM will demonstrate the V/HTR performance and availability of supply chain.

More R&D needed in:

- Coupling between nuclear island and process plant.
- Higher temperature, higher efficiency and wider application ranges.

Among the main takeaways, the need for international cooperation was highlighted.

Q&A session:

- Is the regulator involved in your work? Because one of the main problems is that the regulatory process takes a long time, so the talk with the regulator should take place from early stages of the project.
- Mr Fu indicated that the licensing will be for the nuclear and not for the process heating part.

E. Scientific projects for HTR in Poland

NCBJ – Deputy Director for Innovation and Commercialization – Paweł Sobkowicz

Mr Sobkowicz provided an overview of the NCBJ indicating its areas of research and development. It is the largest research institute with applied and basic research areas, such as:

- particle physics, nuclear physics;
- astrophysics, plasma physics;
- material physics;
- reactor and accelerator physics;
- nuclear energy;
- industry and medical accelerators;
- radioisotope products.

He then provided a deeper insight in research projects related to HTGR ranging from national to international projects. Currently they have four ongoing projects:

- GOSPOSTRATEG-HTR: strategic Polish program of scientific research and development work in preparation of legal, organizational and technical instruments for the HTR implementation. This national project started in 2019 and will imply investments of over EUR 40 million.
- NOMATEN: international program to build new excellence centers in developing countries that are lagging behind. This funding is provided for a long period – 7 years – and with government support it could be longer.

- GEMINI: Nuclear Cogeneration Industrial Initiative. This project has involved the industry as well, a necessary voice for further development towards its goal of contributing to clean and competitive energy beyond electricity by facilitating deployment of nuclear cogeneration plants.
- PhD4GEN: Doctoral studies in reactor physics within the framework of the project "New reactor concepts and safety analyses for the Polish Nuclear Energy Program."

Q&A:

- They have done some work to attract the private companies to participate in their programs, what motivates them to participate, intellectual property?
- Mr Sobkowicz indicated that this is simply economic, intellectual property, access to technology. His understanding and experience show that in most cases the industry is looking into economics, second into the local environments and social acceptance. It is very important not to antagonize the social environment.
- What is the future for the students of the program?
- The hope is that they will stay in Poland. Regarding those who study the nuclear technologies, many are studying the safety codes and modelling and CFD flow, they study HTR but the knowledge they have will be applicable to the regular reactors so their prospects of employment will be quite large.
- Also, since Poland is developing its nuclear program, they will have good job opportunities in the country as well.
- What are the three largest challenges ahead of the technologies?
- Financing, public acceptance (though in Poland it is quite favorable) and technological readiness. Rightly prepared, rightly addressed these projects can be economically viable and sustainable.

F. Chinese HTR program

Tsinghua University – Deputy Chief Engineer, Institute of Nuclear and New Energy Technology (INET) – Li Fu

Mr Fu shared the mission for the HTR in China. Research for the program started in the 70s, among its main goals are to supplement PWRs, to be used for cogeneration and for technology innovation.

The HTR is the reactor for the future for China. Among the latest progress of the project:

- Test of the auxiliary/supporting system started in 2016
- Complete installation in 2019

- Begin commissioning test, reach criticality in 2020
- Achieve full power operation in 2021

The HTR-PM project will provide China with:

- Proven technology and budget: it will be the world's first 200 MWe pebble-bed modular high temperature gas-cooled reactor demonstration plant (HTR-PM).
- Generation IV safety features which will eliminate off-site emergency response through a meltdown-proof reactor.
- Large market potential to provide 200, 600 MWe high efficiency power plant and co-generate steam up to 560°C.
- Development of the whole supply chain.
- More capability from HTR for process heat application, including hydrogen production.
- Fostering all types of international cooperation.

Q&A:

- This reactor is focused on 900 temperature for hydrogen, this poses a limit to the technology. Are there other options other than hydrogen to store energy? Could we store heat?
- Mr Fu explained that the outlet temperature could increase, but for the purpose of the steam generator the 750 temperature is fixed, although it could be higher in the future. The mainstream is for the power plant, not for heat storage.
- What is the final cost, comparable to light water reactors for example?
- The costs depend on the number of plants you deploy. For the first one it would be high, but if you build 10 it would be lower. Compared to others it would be 20% higher – the number of plants you build is very important.
- Who was the founder of this project?
- The government supported this project. In the future, they will operate this project commercially and have the supply chain ready, so they will be able to duplicate and make it quicker.
- Are you planning in developing brittle cycle to benefit from higher efficiency or are the plans to keep the ranking cycles?
- Yes, within the next 20 years we will keep in the steam cycle.
- After describing that there are multiunit operations for the HTR-PM and the HTR-600, is each module operated with one same team or by different?
- It is a separate operator for a separate reactor, in the future they hope that one operator will be able to operate the 2 reactor types.

G. Russian HTR program

State Atomic Energy Corporation "Rosatom" – Vladimir Artisiuk, Councilor, Advisor to Director General

Mr Artisiuk started his presentation by providing an overview of the hydrogen needs and demands by 2050 based on a feasibility study roadmap for the HTGR. Then, moved on to Russia's program concerning the development of hydrogen production. Russia is expecting to become part of the future hydrogen market as producers, with government support both to produce and to use hydrogen in the country while recognizing the need to be ready for the new demands.

Hydrogen power is among the priorities of technology development in Russia with two clear objectives:

- the use of nuclear power beyond electricity, such as process heat, hydrogen production, synfuels, and fuel cells;
- R&D and demonstration of key solutions in nuclear hydrogen power system.

Stages of the program:

- 2019 – project developments of HTGRs for hydrogen production, feasibility studies, roadmaps
- 2020 – 2024: R&D
  - Design of the Reference Unit
  - Key elements of Nuclear Island, methane steam conversion, hydrogen storage and transport, CO_2 utilization, marketing of key elements of hydrogen generation
- 2024 – 2030: construction and commissioning of HTGRs for hydrogen production, establishing infrastructure for hydrogen economy
- 2030 and beyond: large scale environmentally friendly hydrogen production and further infrastructure development for hydrogen economy

To conclude, Mr Artisiuk expressed that the non-electric applications of HTGRs for large-scale environmentally friendly hydrogen production will expand the potential of nuclear power.

International cooperation in the HTGR development is the basis for energy transitions of our energy systems into affordable, reliable, sustainable and low GHG emissions systems.

H. Japanese HTGR program

Japan Atomic Energy Agency (JAEA) – Taiju Shibata, Leader, International Cooperation Group

Mr Shibata indicated that his presentation was focused in the political aspect since his colleague would then present on the technical aspects of the HTGR project in Japan.

Between 2013 and 2017, 8.4% of carbon emissions were reduced in Japan, however, they need to be lowered even more. In order to achieve it, HTGR systems are being considered.

Mr Shibata then introduced the organization of JAEA, with its different areas and activities, including a detailed description of the sector in charge of the VHTR program which is included in the strategic energy plan for the country which was approved in 2018.

The main goal of the plan is to reduce 26% of CO_2 emissions by 2030 and 80% by 2050. This will be achieved with the use of renewables and nuclear energy. The targets are to reach a 22-24% of renewables and 22-20% share of nuclear in power generation by 2030 while phasing out fossil fuel. The final objective is to have a zero fossil fuel energy system by 2050. Between 2030 and 2050 the government will work on the promotion of hydrogen, batteries and a distributed energy system.

How will HTGRs help in this transition?

- HTGR can attain high efficiency (up to 50% in power generation, to 80% for heat utilization rate).
- HTGR may be sited near the demand areas due to its excellent safety features.
- HTGR can be used for non-electric carbon free applications as well, such as hydrogen production and heat.

The road towards commercialization of the gas turbine and the hydrogen HTGR include private companies and international collaboration with JAEA's involvement. Japan's demonstration reactor will be presented to companies around the world.

The roadmap has established milestones to accomplish between 2020 and 2050 for each of the involved parties ranging from the development of the design and demonstration reactors, fuels and materials in 2020-2030; to the construction of the commercial reactor by 2050.

Q&A

- There was mention that HTTR and HGTR can perhaps be deployed near populated areas, near the public. Nowadays the public acceptance and the emergency preparedness and response are very important for the deployment of new reactors. How has JAEA worked in regulatory measures for the deployment of these reactors?
- Mr Shibata indicated that the public has shown allergy to the nuclear power, so it is hard to deploy a new reactor this is why we are focusing in international collaboration, it will be foreign

companies who will be using this tech and in parallel we will carry on this discussions at the IAEA for the safety features of the reactor, and here the safety measures can be discussed though the final determination is not there yet.

- Is there an interest from the non-nuclear industry in Japan to look at hydrogen from nuclear or is it a distant interest?
- Mr Shibata confirmed that the car manufacturers have shown interest, but they do not categorize how to produce the hydrogen, they only focus on its costs.
- When will its commercial deployment take place? And large scale?
- The target is 2040 for the deployment, but it depends on the technology development and the private companies, if they decide that the HTGR meets the requirements of the public.

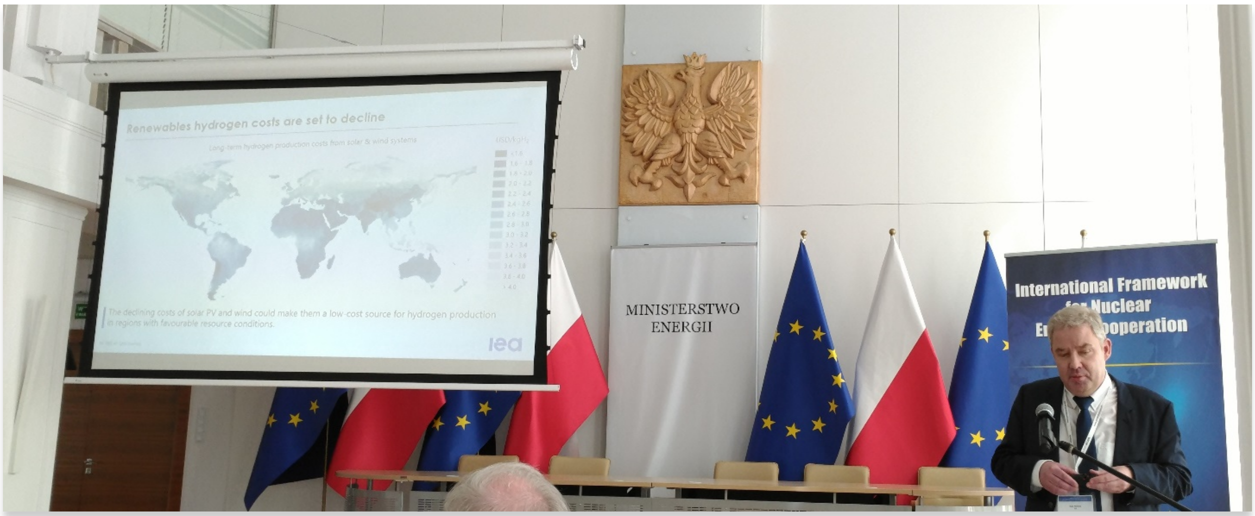
SESSION 3

Future role of Hydrogen and development of innovative nuclear systems

This session included five presentations summarized below

I. The Future of Hydrogen

International Energy Agency – Uwe REMME, Energy Modeller



Mr Remme provided an overview of the advances and status of research for hydrogen and the momentum such is having leading to a promising future for its development. Hydrogen is in everybody's thinking and interest right now and there are good reasons to be excited about hydrogen:

- It can help in the integration of renewables – a few of the options available for long term storage and at a large scale (for months).
- It can help reach the Paris goals, because electrification is discussed today but not every sector can be electrified right away, hydrogen can achieve the remaining climate goal.
- It is good for air pollution in cities.
- It boosts intensification of energy uses since it can be converted to other forms of molecules (methane gas, liquid fuels) allowing it to become easier to transport.

Among the challenges, Mr Remme highlighted: that it is still more expensive than many other energy carriers, the transmission distribution which is holding it back and the fact that today it is produced by carbon emitting sources (such as gas, oil and coal – the cheapest form to extract it today is from gas).

In order to move forward and make this source of energy more cost effective, scaling is important, there are currently 7 projects in operation in combination with CCUs.

The projects have scaled from 1 M.W. a 100 to 200 MW capacity – though they still require government funding, so they are not competitive yet.

Hydrogen is already a very important part of the energy mix. However, if it wants to make significant contributions it has to be used for more applications – power generation, construction, transportation.

It has to build on the exiting users. Replacing from fossil fuels to low carbon emitting producers.

It has been estimated that by 2030 there will be 2.5 billion electric cars on the streets, which could generate further incentives for hydrogen production.

But a bigger push is needed to achieve more affordable costs for it.

Mr Remme identified some opportunities for scaling up hydro towards 2030:

- Creating industrial hubs.
- Using the gas grids could bring down costs.
- Expanding the use of hydrogen in fleets and long corridors – as is being used today for forklifts.
- International Trade – start launching trade routes, even though it is something that might be needed in the long term, it should start now.

And for all these to happen there's a great need for international standards and regulations – international collaboration becomes fundamental.

Q&A session

- For heating with hydrogen, what kind of gas is being burnt?
- Mr Remme indicated that there are demonstration projects to convert the whole distribution into pure hydrogen. One has to look at safety standards and regulations. If we want to decarbonize completely, one has to wonder which are the options to do this and since hydrogen could use the gas grids this would mean less investment.
- What would be the alternative options in a non-hydrogen economy?
- Mr Remme replied that for the heating sector there are other options available. If you move to the industry, the use of CCUs; for transport biofuels (though its potential is limited). There are technical solutions available, but whether they are implementable that's something on which Mr Remme is more skeptical.

J. Nuclear production of hydrogen

Japan Atomic Energy Agency – Xing L. YAN, Deputy Director of Reactor Systems Design Department

Mr Yan opened his presentation by acknowledging that hydrogen production with nuclear energy is a reality today, the question is how attractive it is to produce it. He then provided a very insightful overview going over the different ways in which hydrogen can be produced using nuclear fission reactors, classifying them by energy input (electricity/heat) and feedstock (carbon/water) and the process through which the hydrogen is produced (steam reforming/electrolysis/thermochemical water splitting/hybrid cycle).

Later he focused on HTGR reactors in particular and provided a detailed description, to explain why this reactor type was chosen by JAEA for hydrogen production. Namely, how its passive safety mechanisms ease the co-location to hydrogen processes reducing heat transmission loss and overall costs.

Mr Yan walked the audience through JAEA's hydrogen production demonstration plant which is based in iodine-sulfur thermochemical water-splitting. Consisting of three chemical processes, it requires temperatures ranging from 400 to 900°C and produces no carbon emissions. The project is currently going through HTTR-GT/H2 testing before its commercial deployment.

The project's main goals are to demonstrate nuclear hydrogen and electricity production cogeneration's performance and costs, and, to license nuclear hydrogen production coupled with HTGR. The long-term objective is the production of electricity and hydrogen towards more efficient and less carbon emitting energy systems while moving towards the zero carbon emissions target that Japan has drawn.

Q&A session

- Have you compared the different costs of using electrolysis or using chemical? Which would they be?
- Mr Yan indicated that the target per kg is of 2 USD – which compared to other processes is not very different. He reflected that it is not simple and will take time, 2045 is the target date for the commercial deployment.

K. Micro-reactors for special applications and fuel cycle

URENCO Limited – Chris WHITE, Director, Government Affairs

Mr White went through the fuel cycle's needs and challenges and what URENCO is ready to provide.

He explained how there is a market for enrichment going from 5 to 7% and up to 19.99% for advanced fuels. Next gen fuels with higher burn-up rate hence with longer operating cycles for Gen III, Gen IV, advanced reactors and SMRs. And in order to be able to accommodate such demand there is a need for higher enrichment facilities, deconversion facilities and fabrication facilities.

At the same time solutions are also needed in terms of transport. There is no licenced transport for this kind of fuel at the moment, nor transportable package. They are now testing this kind of package to move the materials.

In terms of legal instruments, there is no prohibition for this sort of transport, so there should not be barriers of this sort to be tackled with.

URENCO has advanced gas centrifuges capable of producing the full span of HA-LEU enrichments with no need for further testing or development. URENCO estimates that if detailed designs, site permits and the contractor selection are undertaken at the same time as the regulatory licensing process, they could build, commission and start-up a HA-LEU production unit within 24 months after obtaining the licensing approval. In fact, for example, in 2019 URENCO was exploring the construction of a dedicated HA-LEU unit at its UUSA facility.

Mr White then moved on to the U-Battery, micro reactor. He explained that the micro reactor has been designed for remote rural communities and for the heavy industry which needs to decarbonize – but it is not built to be connected to the grid. Many small communities depend on diesel, which is both costly and contaminates. It is in these types of places where this kind of technology could be better put at use, it could even offer very sustainable farming options, and be used for mining sites, studies are under way to assess their flexibility. It does not take up too much space so it can be placed next to a small town or a metal factory.

One of the problems is how to bring this technology to those remote places and how to keep the spent fuel. But it is important to say that there is no proliferation risk at all, though of course a safety case is needed. Besides, in theory, the reactor could be operating on its own, with no person on site.

Q&A session

- Do you see bottlenecks for the fuel supply?
- Mr White indicated that they'll have to think about their local markets. It needs government and industry working together to set the fuel cycle infrastructure along with the global market and there needs to be an interest in the national infrastructure to deploy it.
- This is not a fuel factory reactor?
- Mr White replied that they need to strategically take a decision on where the industry wants them to go – bearing in mind all the instruments, but they have to go where the industry takes them.

L. Micro Modular Reactor

Ultra Safe Nuclear Corporation – Francesco VENNERI, Chief Executive Officer

After providing an overview of the company, Mr Venneri went over the facts that make micro reactors a much needed technology.

The logic behind the micro reactor is the immediate need of the remote mining communities which are off grid and need secure and reliable electricity supply. Today they are powered by diesel power generators which are very polluting, and outdated technology.

The micro reactor would bring a carbon free source of energy that operates for 20 years without refueling. After those 20 years the reactor would simply shut down, it will have a one-cycle-lifetime, with no spent fuel to be disposed of. Construction times are from 0 to 3 months.

For other-remote locations the micro reactor is being designed to be refuelled every 6 months.

There are currently 11 micro reactor designs under review in the US, the UK and Canada.

The Chalk River project, in Canada, is currently undergoing the pre licensing process. Mr Venneri provided a detailed overview of the project highlighting its main features and goals:

- production of 15 MWt of process heat which could satisfy the needs of the Chalk River facility and could replace the CO_2 emitting sources currently in place;
- electric power could be supplied to the area grid for 20 years;
- the project will consist of 2 plants: nuclear plant with one or two molten-salt micro reactors providing the process heat to the secondary (adjacent) plant, the adjacent plant which will turn the process heat into energy (electric or other);
- passive safety features which would prevent the reactor from melt down;
- scalable up to ten units with co-located thermal storage;
- site preparation and construction are scheduled from 2021 to 2027, operation from 2023 to 2054.

Q&A session

- How about the projected costs of the project and the availability of investors for the Chalk River project?
- Mr Venneri indicated that it is expensive but manageable, and, that they have investors.
- The reactor is not going to be factory fuelled, the cartridge will be at the plant to then be placed in the reactor. It will not be an operable reactor when it is shipped. The reactor has been designed in order to be constructed as quickly as possible and keeping it simple.

M. Nuclear Innovation 2050: HTGR cogeneration

National Centre for Nuclear Research – Grzegorz WROCHNA, International Cooperation Manager

Mr Wrochna gave the audience a glimpse of Nuclear Innovation 2050 initiative, its goals, focus areas and way forward.

First it was noted that it is not only focusing its discussion on innovative reactors but also innovative fuels. The key questions it addresses are:

- What are the technologies that will be needed in 10 or 30 or 50 years?
- How do we regain the ability to push innovation in the process?

There is a recognized increased need for flexibility, and also of using innovations from other sectors to incorporate into nuclear.

There needs to be a reactor universal enough to be applied for different processes and to cover different needs.

All of these issues can be addressed by making use of the 3 main head-winds identified by the initiative: infrastructure, regulatory framework and costs.

Mr Wrochna then went over the current and upcoming focus areas:

- fuels and materials
- advanced manufacturing and digitalization
- nuclear energy beyond electricity.

Mr Wrochna concluded his presentation with NI2050's vision of demonstrating high-temperature industrial nuclear cogeneration.

Summary of discussions

IFNEC Technical Secretariat

Mr Paillère provided a brief of the topics discussed at the workshop:

- Public acceptance and how we could envisage the deployment of these new technologies and high temperature reactors and non-electric applications, how to talk about the benefits that could come, and how to improve the perception that the public and the young generation in particular have.
- Regulatory framework or frameworks that would enable the deployment. We know that there is some work going on in several agencies – GEN IV Forum for example is working on this. There is work to help develop frameworks for licensing these non-light water reactors.
- Knowledge management – some of these have been developed a long time ago (for example in the Soviet Union) we need to preserve knowledge as we attract new researchers to the sector.
- Major hurdle will be economics, we know that nuclear has to compete with other technologies including fossil fuels – even if there is carbon pricing.
- Innovations in reactor designs, potential for hydrogen as an energy vector – although it is not a low carbon vector if it is not produced with low carbon source, advanced fuels.
- The topic of advanced reactors is a topic that IFNEC will continue to address. Last year in Tokyo with NICE Future, we will have in November a conference hosted by DOE.

The workshop was closed by the IDWG co-chairs, Mr Kubacki expressed his pleasure and honour to have been with all the participants, he gave a special thanks to all the collaborators from the Ministry of Energy of Poland, to the IFNEC Secretariat and his counterpart Alex Burkart, to whom he recognized with a gift and took the opportunity to thank him for the shared meetings. Mr Kubacki also indicated that it was Alex's last workshop as Co-Chair of the Working Group, remembering all the events done together and his great contributions.

Mr Burkart, in turn, thanked everyone present, especially to Zbigniew, and his previous Co-Chair and mentor, John Mathiesson. He took the opportunity to share his experiences as IFNEC's IDWG Co-Chair since the inception of the group.

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