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Nuclear Power in the 21st Century

The International Atomic Energy Agency's mission is to prevent the spread of nuclear weapons and to help all countries — especially in the developing world — benefit from the peaceful, safe and secure use of nuclear science and technology.

Established as an autonomous organization under the United Nations in 1957, the IAEA is the only organization within the UN system with expertise in nuclear technologies. The IAEA's unique specialist laboratories help transfer knowledge and expertise to IAEA Member States in areas such as human health, food, water and the environment.

The IAEA also serves as the global platform for strengthening nuclear security. The IAEA's work also focuses on helping to minimize the risk of nuclear and other radioactive material falling into the hands of terrorists, or of nuclear facilities being subjected to malicious acts.

The IAEA safety standards provide a system of fundamental safety principles and reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation. The IAEA safety standards have been developed for all types of nuclear facilities and activities that serve peaceful purposes, as well as for protective actions to reduce existing radiation risks.

The IAEA also verifies through its inspection system that Member States comply with their commitments under the Nuclear Non-Proliferation Treaty and other non-proliferation agreements to use nuclear material and facilities only for peaceful purposes. The work is multi-faceted and engages a wide variety of partners at the national, regional and international levels. IAEA programmes and budgets are set through decisions of its policymaking bodies — the 35-member Board of Governors and the General Conference of all Member States.

The IAEA is headquartered at the Vienna International Centre. Field and liaison offices are located in Geneva, New York, Tokyo and Toronto. The IAEA operates scientific laboratories in Monaco, Seibersdorf and Vienna. In addition, the IAEA supports and provides funding to the Abdus Salam International Centre for Theoretical Physics, in Trieste, Italy.

Photo: The Sanmen Nuclear Power Station under construction in Sanmen County, Zhejiang Province in China. (China National Nuclear Corporation)

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Cover Photo:
The Bohunice Nuclear Power Plant is a complex of nuclear reactors near the village of Jaslovské Bohunice in Slovakia.
(JAVYS)

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NUCLEAR POWER IN THE 21ST CENTURY

The International Atomic Energy Agency helps its Member States to use nuclear technology for a broad range of peaceful purposes, one of the most important of which is generating electricity.

It will be difficult for the world to achieve the twin goals of ensuring sustainable energy supplies and curbing greenhouse gases without nuclear power.

The accident at the Fukushima Daiichi nuclear power plant in Japan in March 2011 caused anxiety about nuclear safety throughout the world and raised questions about the future of nuclear power.

Two years on, it is clear that the use of nuclear power will continue to grow in the coming decades, although growth will be slower than was anticipated before the accident. Many countries with existing nuclear power programmes plan to expand them. Many new countries, both developed and developing, plan to introduce nuclear power.

The factors contributing to this growing interest include increasing global demand for energy, as well as concerns about climate change, volatile fossil fuel prices, and security of energy supply. It will be difficult for the world to achieve the twin goals of ensuring sustainable energy supplies and curbing greenhouse gases without nuclear power.

The IAEA helps countries that opt for nuclear power to use it safely and securely.

Countries that have decided to phase out nuclear power will have to deal with issues such as plant decommissioning, remediation, and waste management for decades to come. The IAEA also assists in these areas.

I am grateful to the Russian Federation for hosting the 2013 International Ministerial Conference on Nuclear Power in the 21st Century in St Petersburg in June. This timely conference provides a valuable opportunity to take stock of nuclear power in the wake of the Fukushima Daiichi accident.

A high level of public confidence in the safety of nuclear power is essential for the future of the sector. Much valuable work has been done in the past two years to improve safety. But much remains to be done. It is vitally important that the momentum is maintained and that everything is done to ensure that nuclear power is as safe as humanly possible.

This edition of the IAEA Bulletin provides an overview of many of the issues to be addressed at the St Petersburg conference. These include nuclear safety, the role of nuclear power in sustainable development, technological innovation, and nuclear institutions and infrastructure.

I wish the conference participants every success in their deliberations.

Yukiya Amano, IAEA Director General

NUCLEAR POWER, ENERGY ECONOMICS AND ENERGY SECURITY

Economic development requires reliable, affordable electricity that is provided in sufficient quantities to satisfy the minimum energy requirements at a local, regional or national level. As simple as this recipe for economic development appears, technological, infrastructural, financial and developmental considerations must be analysed and balanced to produce a national energy strategy. Complicating that task is the historic fact that energy at the desired price and in the desired quantities can be neither taken for granted nor guaranteed. Energy economics and energy security determine the options available to nations working to establish a sustainable energy strategy for the future.

Energy Economics

A nuclear power reactor is relatively expensive to build but relatively inexpensive to run. That makes it a good investment in some situations, but not in others. It is more attractive where energy demand is growing rapidly, where alternatives are scarce or expensive, where energy supply security is a priority, where reducing air pollution and greenhouse gas emissions is a priority, where financing is available that can wait for longer term returns (which is more characteristic of governments than private industry), and where financial risks are lower due to more predictable electricity demand and prices, stable market structures and strong non-partisan political support. The 68 power reactors currently under construction around the world reflect these characteristics of favourable investment environments. Thirty-eight are in the Far East (29 in China alone), 15 in Eastern Europe, 10 in the Middle East and South Asia, two in Latin America, two in Western Europe and one in North America.

The uranium to fuel nuclear power reactors is found in abundance around the world. At current prices and consumption rates, currently identified conventional uranium resources would last about 80 years. This compares favourably with reserves of 30–50 years for other commodities such as copper, zinc, oil and natural gas. Reprocessing, recycling and the use of fast breeder technology would increase the longevity of the currently identified resources over 60 times to thousands of years.

Energy Security

Another major consideration, in addition to price and resource base considerations, is energy security. The best way to strengthen a country's energy security is by increasing the diversity and resiliency of energy supply options. For many countries, expanding nuclear power would increase diversity in their electricity supplies. Nuclear power has two features that generally further increase resiliency. Firstly, nuclear electricity generating costs are much less sensitive to changes in fuel prices than are fossil-fired electricity generating costs. Secondly, the basic fuel — uranium — is available from diverse producer countries, and small volumes are required, making it easier to establish strategic inventories. In practice, the trend has been away from strategic stocks toward supply security based on a diverse well-functioning market for uranium and fuel supply services. But the option of relatively low-cost strategic inventories remains available for countries that find it important.

Energy Choices

Countries are different. The right energy mix for a country will depend on how fast its energy demand is growing, on the availability of alternatives like hydropower or shale gas, on its financing options, and on its national preferences and priorities as expressed in national politics. How countries balance the various considerations such as accident risks, inexpensive electricity, mitigating climate change, air pollution, jobs, and energy import dependence is at least partly a matter of national preference, and consequently a decision for the IAEA's Member States themselves.

"Moreover," notes IAEA energy planning expert Alan McDonald, "all countries use a mix of energy sources and generate electricity from a mix of technologies." That diversity, McDonald explains, is partly due to historical development as new technologies overlap with older ones, partly because investors disagree about what will prove most profitable, partly because a portfolio of energy sources reduces risk and vulnerability and, where electricity demand is growing especially fast, as in China, partly just to keep up with demand by using all possible options.

ENERGY AND SUSTAINABLE DEVELOPMENT

None of the eight Millennium Development Goals (MDGs) adopted by the United Nations in 2000 directly addressed energy, although for nearly all of them — from eradicating poverty and hunger to improving education and health — progress has depended on greater access to modern energy. Thirteen years later, energy is being given more attention. The target date for the MDGs is 2015, and in 2012 the UN began deliberations to develop sustainable development goals to guide support for sustainable development beyond 2015. *The Future We Want*, the outcome document of the 2012 United Nations Conference on Sustainable Development (also known as Rio+20) gives energy a central role: "We recognize the critical role that energy plays in the development process, as access to sustainable modern energy services contributes to poverty eradication, saves lives, improves health and helps provide for basic human needs."

Nuclear power is ahead of other energy technologies in 'internalizing' all external costs, from safety to waste disposal to decommissioning.

In its Report, *Our Common Future*, published in 1987, the Brundtland Commission* defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," and that has remained the fundamental definition ever since.

Nuclear power's role in sustainable development was thoroughly debated at the ninth session of the UN Commission on Sustainable Development in 2001. While national views differed regarding nuclear power's role in sustainable development strategies, there was unanimous agreement that the choice of nuclear energy rested with countries.

Those who conclude that nuclear power is inconsistent with sustainable development emphasize the risks of nuclear accidents and the fact that there is not yet an operating final repository for high-level nuclear waste.

Those who consider nuclear power an important part of sustainable development emphasize that the Bruntdland Commission's definition of sustainable development focuses on growing assets and opening options — not foreclosing them. Nuclear power broadens the resource base by putting uranium to productive use. It reduces harmful emissions and expands the supply of electricity. Nuclear power increases the world's stock of technological and human capital. And finally, nuclear power is ahead of other energy technologies in 'internalizing' all external costs, from safety to waste disposal to decommissioning. 'Internalizing' costs means that the costs of all of these activities are largely already included in the price we pay for nuclear electricity. Were the environmental costs arising from the use of fossil fuels 'internalized' in the price paid for them, the price we would pay for the electricity produced using fossil fuels would be considerably higher.

National governments need to compare the relative benefits and there needs to be public discussion on the subject.

The first task of sustainable development is often defined as bringing energy, particularly electricity, to the fifth of the world's population without it. For the rural poor, much is being done to make full use of renewable energy technologies that operate in remote areas not connected to electricity grids, says IAEA energy planning expert Alan McDonald. "For the urban poor and the needs of growing megacities, the mix needs to include large centralized power generation to match large centralized power demand. Nuclear power plants provide large amounts of steady power to help meet such demand. Moreover, as countries extend their electricity grids to 'connect the unconnected' and expand electricity access, the benefits of large sources of steady power will become increasingly widespread", McDonald explains.

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*The World Commission on Environment and Development was established by 1983 United Nations General Assembly resolution 38/161 to propose long-term environmental strategies for achieving sustainable development. United Nations Secretary General, Perez de Cuellar, requested the Norwegian Prime Minister, Gro Harlem Brundtland, to chair the World Commission on Environment and Development, often referred to as the 'Brundtland Commission'.

NUCLEAR ENERGY'S ROLE IN MITIGATING CLIMATE CHANGE AND AIR POLLUTION

According to the WHO, air pollution causes over one million premature deaths worldwide each year and contributes to health disorders from respiratory infections, heart disease and lung cancer.
(Photo: istockphoto.com/ ranplett)

Energy experts expect energy demand to rise dramatically in the 21st century, especially in developing countries, where today, over one billion people have no access to modern energy services. Meeting global energy demand will require a 75% expansion in primary energy supply by 2050. If no steps are taken to reduce emissions, the energy-related CO_2 emissions would nearly double in the same period. The increased levels of this greenhouse gas in the atmosphere could raise average global temperatures 3°C or more above pre-industrial levels, which may trigger the dangerous anthropogenic interference with the climate system, which the United Nations Framework Convention on Climate Change seeks to prevent.

Greenhouse Gases and Their Consequences

According to the findings of the Intergovernmental Panel on Climate Change (IPCC), a global warming of more than 3°C will lead to increasingly negative impacts in all regions of the world. In mid-latitude and semi-arid low latitude regions, decreasing water availability and increasing drought will expose hundreds of millions of people to increased water stress.

In agriculture, cereal productivity is expected to decrease in low latitude regions. The increased productivity in mid-latitude and high latitude regions will only partly compensate for this loss. Up to 30% of all terrestrial species will be at a growing risk of extinction.

Ocean acidification will be a consequence of increased carbon emissions. Together with temperature-related coral bleaching, acidification is expected to reduce the ability of shellfish to develop, placing an essential component in the marine food chain at risk. In coastal areas, damage from floods and storms will increase.

Human health will also be affected, especially in less developed countries, by the increasing burden from malnutrition and from diarrhoeal, cardiorespiratory and infectious diseases. Increased morbidity and mortality are foreseen from heat waves, floods and droughts.

The Impact of Air Pollution

The World Health Organization (WHO) has estimated that air pollution causes over 1 million premature deaths worldwide each year.* Air pollution also contributes to health disorders from respiratory infections, heart disease and lung cancer. At the regional scale, air pollutants travelling long distances cause acid rain. Acid rain disturbs ecosystems, leading to adverse impacts on freshwater fisheries and on natural vegetation and crops. Acidification of forest ecosystems can lead to forest degradation and dieback. Acid rain also damages certain building materials and historic and cultural monuments. It is caused by sulphur and nitrogen compounds. Fossil fuel power plants, particularly coal power plants, are the main emitters of the precursors of these compounds.

The amount of emissions avoided through the use of nuclear power is comparable to that avoided through the use of hydropower.

The Challenges of Reducing Greenhouse Gas Emissions

The scientific consensus is that in order to avoid adverse climate change impacts in ecological and socio-economic systems, greenhouse gas emissions must not rise after 2020, and then decline by 50–85% from today's levels by 2050. The world thus faces an enormous mitigation challenge over the next decades.

The IPCC Working Group III and the Synthesis Report from the International Scientific Congress on Climate Change: Global Risks, Challenges and Decisions, held in Copenhagen in 2009, maintain that many mitigation technologies and practices that could reduce greenhouse gas emissions are already commercially available. According to the IPCC, technical solutions and processes could reduce energy intensity in all economic sectors and provide the same output or service with lower emissions. Nuclear power is one of the mitigation options available today.

Over the past 50 years, electricity generation through nuclear power avoided significant amounts of greenhouse gas emissions around the world. Globally, the amount of emissions avoided through the use of nuclear power is comparable to that avoided through the use of hydropower. Hydropower, nuclear power plants and wind based electricity are among the lowest CO_2 emitters when emissions are considered over the entire energy life cycle.

In future, greenhouse gas emissions from nuclear energy technologies will be even lower thanks to advances in uranium enrichment technology that require much less electricity; extended nuclear power plant lifetimes (which means reduced emissions per kilowatt-hour associated with construction); and increased fuel burnup (which means reduced emissions per kilowatt-hour associated with uranium mining and manufacturing fuel).

The IPCC has estimated the mitigation potential of various electricity generating technologies and determined that nuclear power represents the greatest mitigation potential at the lowest average cost in the energy supply sector, essentially electricity generation. Nuclear power has the potential to continue to play a significant role in the effort to limit future greenhouse gas emissions while meeting global energy needs.

Air Pollution Mitigation Through Nuclear Power

Nuclear power plants emit virtually no air pollutants during their operation. In contrast, fossil fuel power plants are major contributors to air pollution. According to the WHO, a significant reduction of exposure to air pollution can be achieved by lowering the concentrations of several of the most common air pollutants emitted during the combustion of fossil fuels.

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*Air quality and health, Fact sheet N°313, updated September 2011, www.who.int/mediacentre/factsheets/fs313/en/

NUCLEAR POWER TODAY AND TOMORROW

Worldwide, with 437 nuclear power reactors in operation and 68 new reactors under construction, nuclear power's global generating capacity reached 372.5 GW(e) at the end of 2012. Despite public scepticism, and in some cases fear, which arose following the March 2011 Fukushima Daiichi nuclear accident, two years later the demand for nuclear power continues to grow steadily, albeit at a slower pace.

A significant number of countries are pressing ahead with plans to implement or expand their nuclear power programmes because the drivers toward nuclear power that were present before Fukushima have not changed. These drivers include climate change, limited fossil fuel supply, and concerns about energy security.

Globally, nuclear power looks set to continue to grow steadily, although more slowly than was expected before the Fukushima Daiichi nuclear accident. The IAEA's latest projections show a steady rise in the number of nuclear power plants in the world in the next 20 years. They project a growth in nuclear power capacity by 23% by 2030 in the low projection and by 100% in the high projection. Most new nuclear power reactors planned or under construction are in Asia.

In 2012 construction began on seven nuclear power plants: Fuqing 4, Shidaowan 1, Tianwan 3 and Yangjiang 4 in China; Shin Ulchin 1 in Korea; Baltiisk 1 in Russia; and Barakah 1 in the United Arab Emirates. This increase from the previous year's figures indicates an on-going interest and commitment to nuclear power and demonstrates that nuclear power is resilient.

Countries are demanding new, innovative reactor designs from vendors to meet strict requirements for safety, national grid capacity, size and construction time, which is a sign that nuclear power is set to keep growing over the next few decades.

Safety

Such growth in the sector must of course be accompanied by increased safety. The Fukushima Daiichi nuclear accident has been described as a wake-up call for everyone involved in nuclear power. According to IAEA Director General Yukiya Amano, the accident reminded us that safety can never be taken for granted, even in advanced industrial countries with considerable experience of using nuclear energy.

Important lessons have been learned, although further lessons may yet be learned. We have quickly been able to absorb the safety lessons from the accident and help Member States apply them in operating reactors around the world. Nuclear reactors have become safer than they were before the accident, like in many other industries. In fact, since the Chernobyl accident in 1986, the international regime for nuclear safety has grown significantly stronger. Today, many internationally binding legal mechanisms have been brought into force, such as the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which help form a web of support around the IAEA Member States and pushes the global nuclear industry towards continuous improvement of nuclear safety.

Planning for Nuclear Power

As many countries, the so-called 'newcomers', continue to consider introducing nuclear power into their energy mix, the IAEA offers a number of services to help them evaluate their readiness and make informed decisions. These services range from assisting Member States in building their energy planning capabilities, independent of any interest in nuclear power, to supporting long range strategic nuclear energy planning and aiding national infrastructure development, including for radioactive waste management and decommissioning.

Throughout the different stages of development of Member States' nuclear power programmes, we provide integrated services to help Member States ensure the safe, secure, responsible and reliable use of nuclear energy.

Alexander Bychkov, IAEA Deputy Director General and Head of the Department of Nuclear Energy.

SUPPORTING NEW NUCLEAR POWER PROGRAMMES

The decision to introduce nuclear power is one of the most far-reaching policy choices a government can make. It is a complex decision. A nuclear power programme is a commitment of at least a century, from planning, through construction, to operation, waste management and eventually decommissioning. "It is a sophisticated technology that requires sophisticated planning, yet the countries that are now considering a nuclear power programme can rely upon the cumulative experience that over 30 operating countries have acquired in the past 50 years, and the systematic support provided by the IAEA", states Anne Starz, Head of the Integrated Nuclear Infrastructure Group at the IAEA.

The IAEA provides rational, structured guidance for nuclear power introduction through the 'Milestones' approach.

The step from 'newcomer' to operator requires up to two decades of planning, licensing and construction before the plant delivers electricity. Thirty years ago, a country building its first nuclear power plant did not have the network of international and bilateral support that newcomers can call upon today. Specialized knowledge is available via international and bilateral cooperation to help newcomers establish the necessary legal, regulatory and human infrastructure. In addition, newcomers profit from the know-how acquired through three decades of nuclear safety peer reviews, expertise in developing human resources and management systems, energy planning, feasibility studies, site selection, technology assessment, handling financial risks, and managing waste.

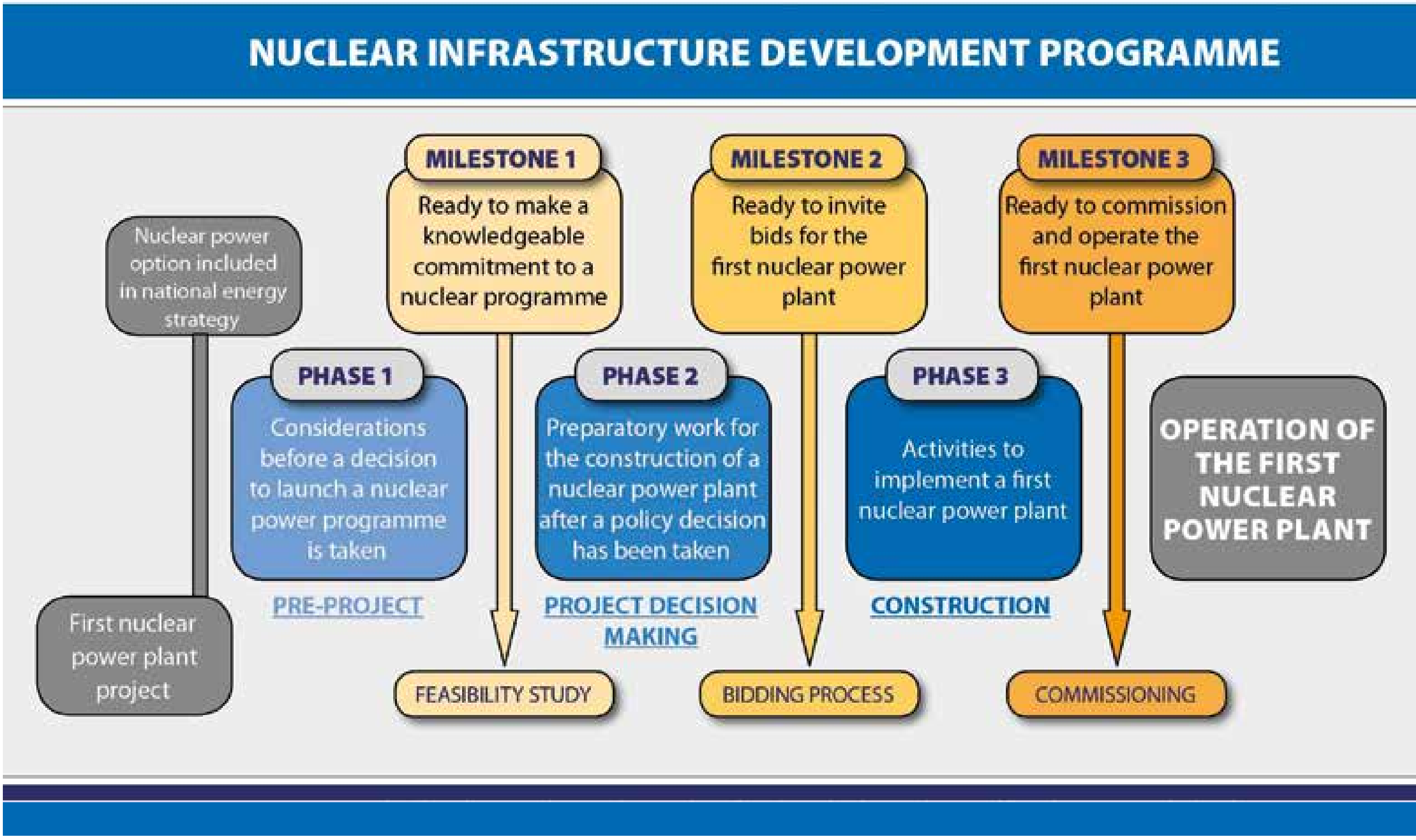
"There are no shortcuts", Starz explains. "Newcomers have more to learn than their predecessors had to master 30 years ago, yet we find that since they are starting from the very beginning, many lessons learned have been acquired and expensive mistakes can be avoided. They are not alone in this enterprise, as they might have been years ago when countries were pioneering this technology."

The IAEA Member States that are actively working towards introducing a nuclear power programme, and those that are considering that decision, share several main challenges. They need to find a method to cement support for a project that will begin to provide a return on investment several years after the decision is taken to pursue nuclear power. "It is much more likely that a country will be able to sustain the policy to introduce nuclear power, if all of the main governmental actors and stakeholders are aligned in their commitment to the enterprise. That is one of the main purposes of systematic stakeholder involvement", Starz says.

For many developing countries, the relatively large capital investment needed to fund the reactor's construction can become one of the major obstacles. The IAEA supports countries in identifying means to handle the financial risks.

Another issue that arises early in the planning is the need for an experienced nuclear workforce, which probably does not exist when the decision is taken to introduce nuclear power. Starz explains that human resource development is a classic 'chicken-and-egg' problem: "How can a country train people to safely operate the nuclear power plant, if no power plant exists? By the same token, countries need to know how to employ experienced people, if the nuclear power plant is not yet operational." The answer lies in workforce planning and human resource development, two areas in which the IAEA also provides support.

Another challenge, waste management, needs to be explained through stakeholder and public outreach. Starz explains, "Planning for waste management is like deciding how and when the airplane will land before it takes off". Nuclear safety is another extremely important area that is closely scrutinized by the public and the stakeholders. Following the Fukushima Daiichi nuclear accident, "Public confidence in nuclear power was shaken. Yet we see in those countries that are actively pursuing the introduction of a nuclear power programme, as well as in some countries with



established nuclear power programmes, that public sentiment is elastic and has shifted to a supportive stance," adds Starz.

Since the Fukushima Daiichi nuclear accident in March 2011, one IAEA Member State began constructing its first nuclear power plant. This was a notable development since it was the first time in 27 years that any newcomer had started construction of its first plant. Two more countries ordered their first nuclear power plants and another six have decided to introduce nuclear power and are actively preparing the related infrastructure.

All the countries that are introducing nuclear power will be making significant infrastructural decisions over the course of the coming decades. That decision-making process entails much more than technical considerations, such as choosing a reactor technology, site selection or capacity development. "The IAEA provides rational, structured guidance for nuclear power introduction through the 'Milestones' approach, which provides Member States with a methodology they can use to mark progress during the planning stages and to demonstrate their commitment to nuclear safety and control of nuclear materials. It emphasizes the need to build consensus on a decision that will affect many generations", Starz notes.

IAEA guidance to newcomers was reviewed extensively after the Fukushima Daiichi nuclear accident. While the Milestones approach remains valid, greater emphasis will be placed on the role of the future owner-operator who has the primary responsibility for safety.

There is growing interest among IAEA Member States for IAEA support in reviewing nuclear power infrastructures in a systematic and integrated manner. Both established operators and newcomers have requested comprehensive, international peer reviews organized by the IAEA to assess progress in introducing nuclear power, or in an existing programme's expansion. "With this guidance on the Milestones, the IAEA has set the bar higher for countries that wish to demonstrate progress, and, as a result, we see that this guidance is valued both by the newcomers and the established operators as it ensures a safer and more sustainable nuclear power programme", Starz concludes.

SOLUTIONS FOR WASTE MANAGEMENT

Finland built a large system of underground tunnels in solid rock designed to last for at least 100,000 years. The final repository will be located in Olkiluoto, approximately 300 km northwest of Helsinki. (Photo: Posiva, Finland)

To safely and securely dispose of high-level and long-lived radioactive waste, this material needs to be stored for a period of time that is very long compared to our everyday experience. Underground disposal facilities need to be designed and constructed in suitable geological conditions that can be confidently demonstrated to contain and isolate the hazardous waste from our environment for hundreds of thousands of years.

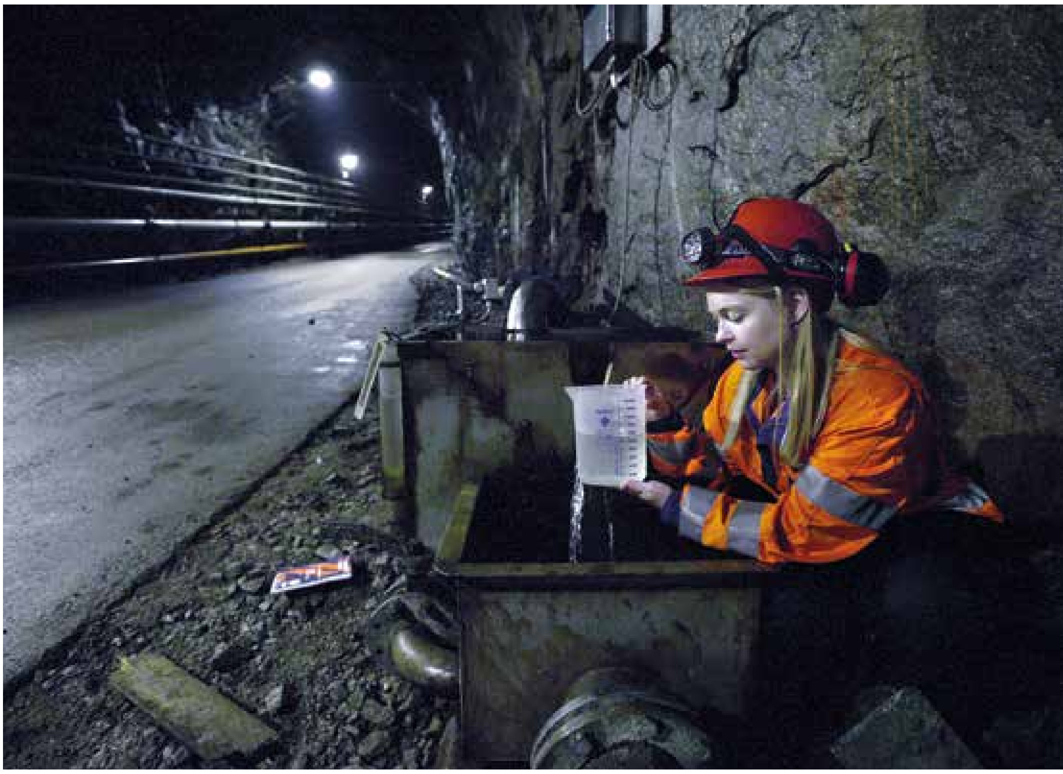
Over this period of time, during which the safety of an underground waste repository system must be assured, the waste's radioactivity will decay to a level that cannot pose a danger to people or the environment. The archaeological record can help in visualizing such a long period of time. Climates change, oceans rise and vanish, and species evolve in the course of a one hundred millennia. Rocks bear witness to all of these changes. Geologists in their search for safe repositories for the long-term disposal of high level radioactive waste have identified rock formations that have proven stable for millions of years. These geological formations are expected to remain stable for millions of years and can serve as host formations for waste repositories.

The waste with the highest radioactive content includes spent nuclear fuel, when declared as waste, and by-products of fuel reprocessing activities. This type of high-level radioactive waste must be carefully isolated from the biosphere. In the consensus opinion of international experts, deep geological formations should be used to host final repositories for the safe disposal of this waste. Currently, a number of countries are pursuing the geological disposal of high-level waste. Geological facilities already exist in Germany and the USA for the disposal of low- and intermediate-level waste.

Other sites, in Finland, France and Sweden are being developed for the disposal of high level radioactive waste and spent nuclear fuel and, subject to regulatory approvals, are due to begin waste emplacement operations in the 2020s.

In several countries, scientists are testing disposal techniques and investigating geological conditions in specially built underground laboratories to be certain that the waste in a repository will remain isolated from people and the environment for the next 10,000 generations. Typically, safety experts assess repository safety over a period of up to, and in some cases, beyond a million years.

Research performed in these underground laboratories has demonstrated the viability of disposal in salt (Germany), crystalline rock (Canada, Japan, Switzerland, and Sweden), plastic clay (Belgium), and claystone (France and Switzerland). Russia is planning to construct an underground research laboratory in the Krasnoyarsk region in central Siberia from 2015. China is planning an underground research laboratory, which would be operational before 2020.



A worker in the underground tunnel in Forsmark, a village on the east coast of Uppland in Sweden. (Photo: SKB Sweden)

In Belgium, the High-Activity Disposal Experimental Site Underground Research Facility, or HADES, is situated in a clay formation at a depth of over 220 metres. It is the leading research facility in Belgium for experimental research on the deep geological disposal of radioactive waste.

The Czech Republic is researching geological repository options that will result in the emplacement of high-level waste in a granite rock mass or a similar environment, a concept comparable to Sweden's and Finland's designs.

In Finland, scientists started the research for a final waste repository in the 1970s. In December 2012, Posiva, the Finnish company in charge of siting and implementing a spent fuel repository, submitted a licence application to build the repository at Olkiluoto, located approximately 300 km northwest of Helsinki. Waste emplacement, provided a licence is granted by the regulator, is scheduled to start in 2020.

In an underground laboratory located outside Bure in northeast France, the French National Radioactive Waste Management Agency (Andra) is testing the capacity of the rocks to contain and isolate high-level radioactive waste for several hundreds of thousands of years.

In Japan, the Mizunami Underground Research Laboratory Project investigates, analyses and assesses the deep geological environment and develops engineering technologies for application deep underground. A second laboratory situated at Horonobe, on the island of Hokkaido, studies the deep geological environment in sedimentary rocks.

In Sweden, the Swedish Nuclear Fuel and Waste Management Company (SKB) selected a disposal facility site close to Forsmark on the east coast of Uppland and submitted a licence application to build the spent fuel repository in March 2011, which is currently undergoing regulatory review.

In the consensus opinion of international experts, deep geological formations should be used to host final repositories for the safe disposal of this waste.

Switzerland has two underground research laboratories — in the Swiss Alps, lies the Grimsel Test Site and a second research facility is located at Mont Terri — which provide environments to realistically test geological conditions, equipment and disposal options for high-level radioactive waste disposal.

BUILDING PUBLIC TRUST IN NUCLEAR POWER

Stakeholder involvement is recognized as a crucial process for the success of any nuclear power programme. Failing to effectively engage with stakeholders such as policy- and decision-makers, media, community members, and the public in general can have negative consequences, says Brenda Pagannone, specialist in stakeholder involvement in the IAEA's Nuclear Power Engineering Section. Shaken public trust may lead to delays, and delays are costly for the operator, and the country, and challenging for populations in need of energy.

The purpose of stakeholder involvement is to help people understand the rationale behind the competent authorities' decisions.

IAEA Member States are increasingly requesting IAEA assistance in their efforts to engage stakeholders. The IAEA is responding to these requests by organizing training and developing guidelines to share expertise and experience and by reviewing national communication strategies. In all of these activities, the IAEA strongly encourages Member States to involve stakeholders throughout the lifecycle of the nuclear power programme. Although each country has specific sets of stakeholders with unique needs and concerns, some principles apply widely.

"Openness and transparency, and understanding that the purpose of stakeholder involvement isn't always about gaining complete public acceptance", Pagannone highlighted. "Rather, its aim is to help people understand the rationale behind the competent authorities' decisions."

The IAEA further advocates that countries initiate dialogue with stakeholders as soon as a nuclear power programme is being considered, demonstrating accountability and building trust, as well as reaching out to younger generations.

The complexity of nuclear technology has sometimes led experts to underestimate the importance of communication. "Often, we've heard from experts, 'We know what's best for you. We know it's safe. Trust us,'" Pagannone explains. "Today, the media are ever-present, information is easily available and credibility is based not solely on competence, but also on the ability to explain why a decision was taken."

Sharing complex information in a manner that can be understood by a general audience is just part of the process. The nuclear industry and authorities must hear their stakeholders' concerns. "Listening to them and empathizing with their concerns is important. And then, wherever possible, you need to address those concerns," Pagannone says.

All organizations involved should clearly communicate their role in the nuclear power programme, and the stakeholders' role in the process. "It is very important to clarify the expectations of the stakeholders right away, so they know what type of impact they may have on the programme," Pagannone notes.

To start the process, stakeholders must be identified, including groups with critical concerns about nuclear power. "Stakeholder engagement means being open also to the other side, to the challenge," Pagannone says. "It is by accepting that challenge that you can aim to respect other views."

TRAINING TOMORROW'S NUCLEAR WORKFORCE

Start with the children. That is the message Brian Molloy, a human resources expert in the IAEA's Nuclear Power Engineering Section, wants to convey to any country considering launching or expanding a nuclear power programme. Mathematics and science curricular and extra-curricular activities at secondary and even primary schools are of crucial importance to future recruiting efforts at nuclear power plants, he says: "You need to interest children in science and physics and engineering. The teaching needs to be robust enough to teach them, but it must also gain their interest."

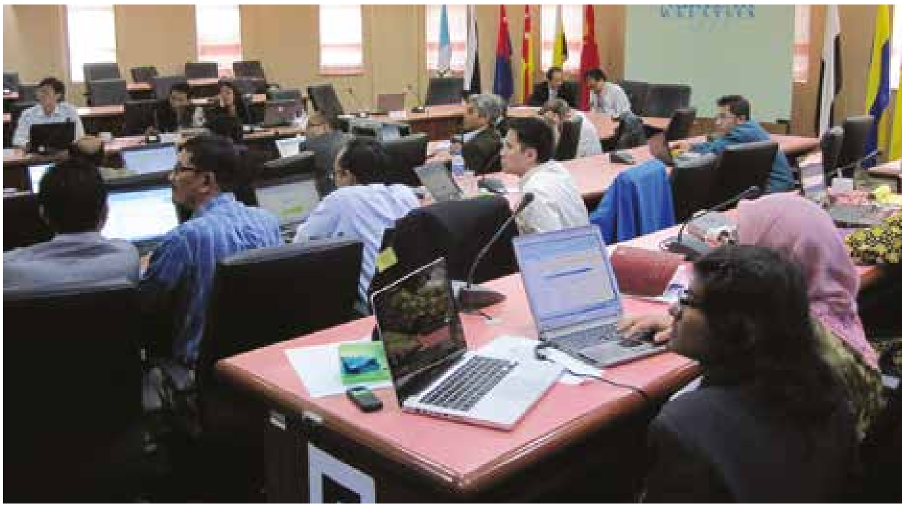
Recruiting high-calibre engineers needed for the operation of nuclear power plants is a growing challenge, even for existing nuclear power programmes, because of a wave of retirements combined with increasing global demand. But essential as engineers are, they are only a component of the staff at any nuclear power plant. In fact, most employees at nuclear power plants are not university graduates — they are skilled technicians, electricians, welders, fitters, riggers and people in similar trades. Molloy argues that this part of the workforce needs more focus. "It's about getting a balance between focusing on the academic and the skilled vocational", he says, adding that countries considering nuclear power programmes often initially place undue focus on nuclear engineers.

Planning the nuclear workforce of the future begins up to 10 years before the trained staff will need to be recruited. Education and training begins from an early school age when the curriculum already includes a firm grounding in science and mathematics. "Several years of science and maths education, as well as training, are needed to build up a knowledge level in society through the education system and through outreach", Molloy says. Other key components of human resources management in the nuclear power field include continuous education and succession planning to ensure that personnel turnover is anticipated and skilled staff can be replaced in smooth succession. The IAEA offers its Member States wide-ranging support in human resources management through workshops, technical meetings, assessments and professional advice.

IAEA publications such as *Milestones in the Development of a National Infrastructure for Nuclear Power, Managing Human Resources in the Field of Nuclear Energy and Workforce Planning for New Nuclear Power Programmes* provide guidelines. The IAEA's Integrated Nuclear Infrastructure Reviews highlight human resource development as one of the 19 infrastructure issues. The IAEA has a Technical Working Group on Managing Human Resources in the Field of Nuclear Energy to provide advice and support in all areas of human resource management. The IAEA has also developed a core curriculum for nuclear engineering that can be used by universities.

By adopting the IAEA Action Plan on Nuclear Safety, IAEA Member States emphasized the importance of human resource management. One of the Action Plan's 12 actions calls on countries with operating or planned nuclear power programmes to strengthen capacity-building programmes to "continuously ensure sufficient and competent human resources necessary to assume their responsibility for safe, responsible and sustainable use of nuclear technologies." The Action Plan also calls on the IAEA Secretariat to assist as Member States requested.

Such assistance is in high demand in newcomer countries, but, according to Molloy, human resource management is just as important in countries that already operate nuclear power plants. He highlighted the example of the Finnish Government's demand that utilities review the national nuclear capability as a condition of clearance for expansion as a useful approach. "They looked at whether they had enough human resources to build and operate the plants in the long run", Molloy says. "That is a very good model."



The IAEA offers its Member States wide-ranging support in human resources management through workshops, technical meetings, assessments and professional advice.
(Photo: IAEA)

NUCLEAR SAFETY THROUGH INTERNATIONAL COOPERATION

The Fukushima Daiichi nuclear accident was the worst at a nuclear facility since the Chernobyl accident in 1986. It caused deep public anxiety and damaged confidence in nuclear power. Following this accident, strengthening nuclear safety standards and emergency response has become an imperative at the global level. The IAEA is leading in developing a global approach, and the IAEA Action Plan on Nuclear Safety is providing a comprehensive framework and acting as a significant driving force to identify lessons learned and to implement safety improvements.

Strengthening nuclear safety is addressed through a number of measures proposed in the Action Plan including 12 main actions focusing on safety assessments in the light of the accident. Significant progress has been made in assessing safety vulnerabilities of nuclear power plants, strengthening the IAEA's peer review services, improvements in emergency preparedness and response capabilities, strengthening and maintaining capacity building, as well as widening the scope and enhancing communication and information sharing with Member States, international organizations and the public. Progress has also been made in reviewing the IAEA's safety standards, which continue to be widely applied by regulators, operators and the nuclear industry in general, with increased attention and focus on accident prevention, in particular severe accidents, and emergency preparedness and response.

Strengthening the Global Nuclear Safety Framework

The IAEA's safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from ionizing radiation. To assist Member States in implementing these standards and enabling valuable experience and insights to be shared, the IAEA provides a variety of advisory services and peer review missions on design, siting and engineering, operational, radiation, transport safety, as well as radiation protection and the safe management of radioactive waste.

The IAEA's safety standards represent a harmonized and globally accepted body of guidance, requirements and standards. To continuously improve these standards, we gather feedback from Member States on their implementation and then incorporate this information into subsequent revisions of the standards; this helps ensure that they continue to meet Member States' needs. The process used for the review and revision of the IAEA's safety standards in the wake of the Fukushima Daiichi nuclear accident is not different in essence. This is another illustration of the continuous efforts to achieve ever higher levels of safety.

Since the Fukushima Daiichi nuclear accident, the designs of many existing nuclear power plants, as well as the designs for new nuclear power plants, have been enhanced. This includes additional measures to mitigate the consequences of complex accident sequences involving multiple failures and of severe accidents. Complementary systems and equipment with new capabilities have been backfitted to many existing nuclear power plants to help to prevent severe accidents and to mitigate their consequences. Guidance on the mitigation of the consequences of severe accidents has been provided at all existing nuclear power plants as all vendor owners' groups have developed generic severe accident management guidelines (SAMGs) to be used as a basis for the development of plant specific SAMGs. The IAEA is strongly promoting plant-specific development through our peer review missions. The design of new nuclear power plants now explicitly includes the consideration of severe accident scenarios and strategies for their management.

Standards, guides and codes are essential for the safe operation of nuclear facilities. But they are not enough. They must be implemented and accompanied by expert peer reviews. Strengthening and expanding the global nuclear safety framework is, therefore, dependent upon the strong commitment, full cooperation, collaborative participation and complete involvement of the entire nuclear community to support the continuous work of the IAEA for future generations.

Denis Flory, IAEA Deputy Director General and Head of the Department of Nuclear Safety and Security.

ACHIEVING NUCLEAR SUSTAINABILITY THROUGH INNOVATION

In 2000, the IAEA Member States recognized that concerted and coordinated research and development is needed to drive innovation that ensures that nuclear energy can help meet energy needs sustainably in the 21st century. Following an IAEA General Conference resolution, an international 'think tank' and dialogue forum were established. The resulting organization, the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), helps nuclear technology holders and users coordinate the national and international studies, research and other activities needed to achieve innovations in nuclear reactor designs and fuel cycles. Currently, 38 countries plus the European Commission are participating in the project. This group includes both developing and developed economies that represent more than 75% of the world's population and 85% of its gross domestic product.

INPRO undertakes collaborative projects among IAEA Member States, which analyse development scenarios and examine how nuclear energy can support the United Nations' goals for sustainable development in the 21st century. The results of these projects can be applied by IAEA Member States in their national nuclear energy strategies and can lead to international cooperation resulting in beneficial innovations in nuclear energy technology and its deployment. For example, INPRO studies the 'back end' of the fuel cycle, including recycling of spent fuel to increase resource use efficiency and to reduce the waste disposal burdens.

National nuclear energy planners and IAEA INPRO experts also work together to conduct national Nuclear Energy System Assessments (NESAs) that help planners make informed decisions regarding the sustainability of their strategic deployment plans. This assessment work is performed using the INPRO methodology, a tool developed through extensive cooperation with Member State experts, to determine whether a nuclear energy system strategy, including specific technology choices, can sustainably meet energy needs in the years to come. Several key areas are taken into account, such as competitive energy economics; national legal, institutional and industrial infrastructures; the environmental impact; proliferation resistance; physical protection; and the inherent safety of the reactors and nuclear fuel cycles.

The INPRO project also studies current innovations in reactor technology. For example, case studies have been developed and analysed to gain a better understanding of the performance of passive safety features in the advanced pressurized heavy water reactor in India and the advanced power reactor plus (APR+) in the Republic of Korea. INPRO members have jointly investigated the technological challenges of cooling reactor cores that operate at high-temperatures in advanced fast reactors, high temperature reactors and accelerator driven systems that use liquid metals and molten salts as coolants. An INPRO study also addressed legal and institutional issues related to the introduction of transportable nuclear power plants. The results of INPRO's studies aim to help technology developers learn about innovative technologies that could simplify the introduction and deployment of next generation nuclear power plants and related infrastructure issues that must be addressed.

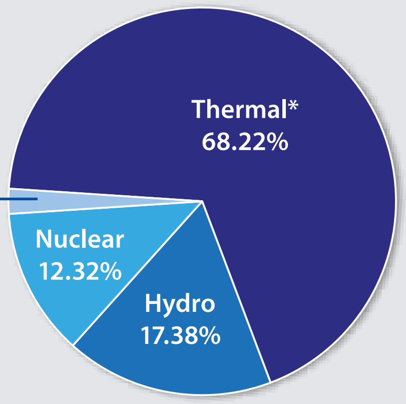
Since the Fukushima Daiichi accident, increased attention is being given to finding ways to prevent severe accidents and to mitigate their consequences, including the release of radioactive material to the environment. A new INPRO study will examine the safety requirements and related technical and institutional innovations that could prevent radioactive releases that require relocation or evacuation of people from the vicinity of a nuclear power plant in case of an accident. INPRO and the Generation IV International Forum (GIF) are the only multilateral international cooperative groups that are supporting research and development for the next-generation of nuclear reactors. GIF coordinates research activities on six next generation nuclear energy systems: sodium fast reactors, lead fast reactors, gas fast reactors, molten salt reactors, supercritical water reactors, and very high-temperature reactors. INPRO and GIF experts cooperate and exchange information on projects of mutual interest. GIF regularly presents the technical development status of each of the reactors under development within the participating GIF Member States. INPRO and GIF collaborate mainly in the areas of safety, proliferation resistance and the economics of innovative nuclear reactors.

In 2010, INPRO established a formal Dialogue Forum on Global Nuclear Energy Sustainability. Since then, all IAEA Member States and qualified stakeholder groups have been invited to participate in a broad technical exchange on topics of mutual interest related to nuclear sustainability in the 21st century.

KEY STATISTICS

Contribution of Each Fuel Type to Electricity Generation

as of December 2011, in percentage



*Thermal is the total for solids, liquids, gases, biomass and waste.

**Renewables is the total for geothermal, wind, solar and tide energy.

Source: IAEA

Total Number of Reactors Worldwide, as of March 2013

Country	In Operation	Total Net Electrical Capacity (MW)	Under Construction
Argentina	2	935	1
Armenia	1	375	
Belgium	7	5927	
Brazil	2	1884	1
Bulgaria	2	1906	
Canada	19	13500	
China	18	13860	28
Czech Republic	6	3804	
Finland	4	2752	1
France	58	63130	1
Germany	9	12068	
Hungary	4	1889	
India	20	4391	7
Iran, Islamic Republic of	1	915	
Japan	50	44215	2
Korea, Republic of	23	20739	4
Mexico	2	1530	
Netherlands	1	482	
Pakistan	3	725	2
Romania	2	1300	
Russia	33	23643	11
Slovakia	4	1816	2
Slovenia	1	688	
South Africa	2	1860	
Spain	8	7560	
Sweden	10	9395	
Switzerland	5	3278	
Ukraine	15	13107	2
United Kingdom	16	9231	
United Arab Emirates			1
United States of America	103	100680	3
Total	**437**	**372613**	**68**
	The total includes 6 reactors in Taiwan, China		The total includes 2 reactors in Taiwan, China

Source: IAEA

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