IAEA BULLETIN

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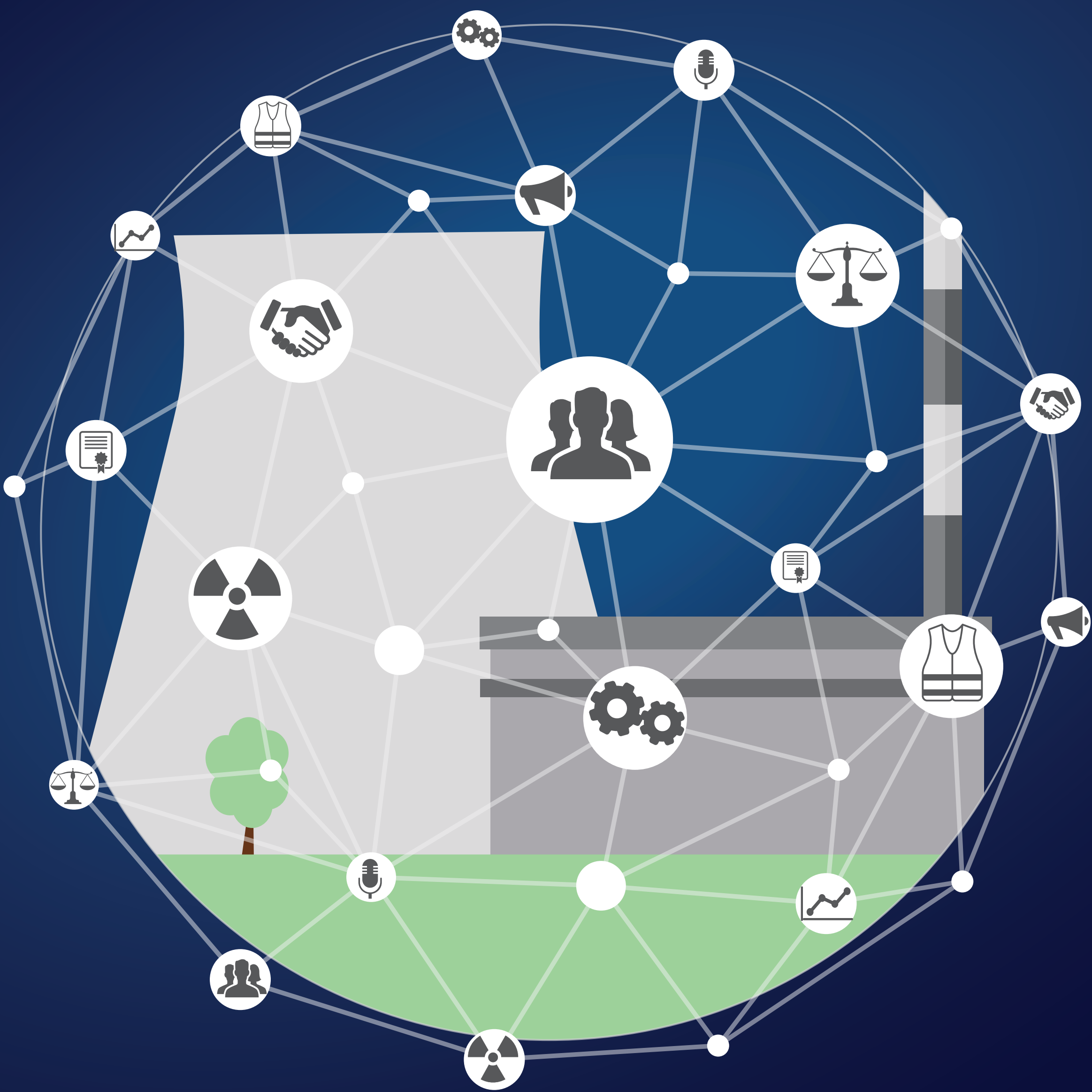
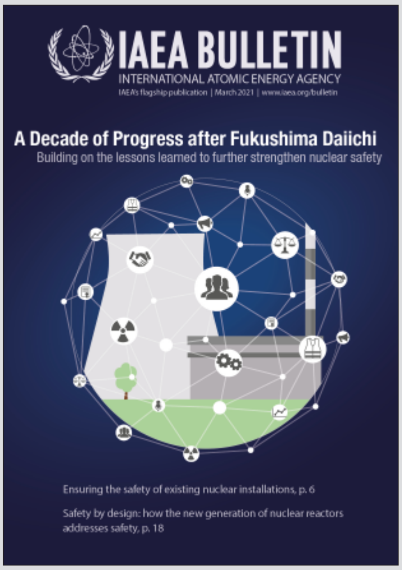
A Decade of Progress after Fukushima Daiichi

Building on the lessons learned to further strengthen nuclear safety





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Office of Public Information
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International Atomic Energy Agency
Vienna International Centre
PO Box 100, 1400 Vienna, Austria
Phone: (43-1) 2600-0
iaeabulletin@iaea.org

Managing Editor: Laura Gil
Editor: Miklos Gaspar
Design and production: Ritu Kenn

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IAEA

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, industry and the environment.

The IAEA also serves as the global platform for strengthening nuclear security. The IAEA has established the Nuclear Security Series of international consensus guidance publications on 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 and criminals, 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 IAEA's 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.

Ten years after the Fukushima Daiichi accident: stronger nuclear safety, globally

By Rafael Mariano Grossi, Director General, IAEA

On 11 March 2011, the Great Japanese Earthquake shook the Asian seabed so powerfully that it moved the main island of Japan two and a half metres to the east.

As the ensuing tsunami swept across the mainland, it breached Japan's coastal defences including the perimeter of the Fukushima Daiichi's Nuclear Power Plant, causing the release of radionuclides. Even so, scientists have found no evidence that this radiation caused health-related effects.

The accident prompted a concerted and coordinated response by the international community, which has led to a significant improvement in the safety and safety culture in the nuclear sector. Three months after the accident, the IAEA hosted a Ministerial Conference on Nuclear Safety and the IAEA Action Plan on Nuclear Safety was endorsed in September 2011.

Nuclear engineers worldwide poured over their reactors analysing and upgrading equipment. They shared their knowledge and findings and four years later, the IAEA published its comprehensive report on the accident.

It is important to recognize the progress made in nuclear safety in Japan and worldwide in the past decade. Nuclear is safer than it has ever been. Nonetheless, we cannot be complacent. I continue to emphasize the need to remain vigilant and put safety first. The 7.3-magnitude earthquake that hit Fukushima in 2021 is a reminder of the need to keep our safety focus.

The stakes are even higher today, because we need nuclear power to expand if we are to avoid the worst consequences of climate change.

Nuclear safety requires effective international cooperation. The IAEA is where much of this cooperation takes place. Therefore, I invite you to read this edition of the *IAEA Bulletin*, in which we provide an overview of the important efforts made in global safety since 2011.

You will learn about efforts by partner organizations during and after the accident (p. 4). You will read about the safety measures put in place (p. 6). On page 8, we describe how we prepare for nuclear and radiological emergencies and, on page 10, how we communicate with the public to minimize fear. Our article on page 12 describes the accident and what caused it. We explain how the IAEA safety standards have been reviewed to reflect the lessons learned (p. 14).

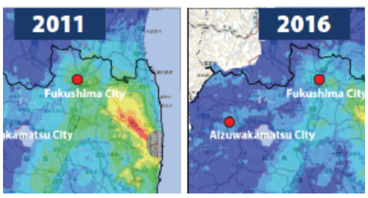
You will learn how the Fukushima Prefecture, with the support of the IAEA, has tackled one of the most complex nuclear clean-ups in history (page 16). We provide an overview of how innovation in design can contribute to safety (p. 18), and we look at ways of spurring interest in nuclear power among young people (p. 20). We explain how we promote safety culture (p. 22) and explore how international legal instruments have made liability and safety frameworks more robust since 2011 (p. 24).

As you read this edition, you will see that the IAEA and the international community have made huge strides in the past decade. Nevertheless, our task of strengthening safety never stops. In that vein, we will host the International Conference on a Decade of Progress After Fukushima Daiichi: Building on Lessons Learned to Further Strengthen Nuclear Safety in November. Until then, you can count on us to stay vigilant and get the work done.

"We cannot be complacent. I continue to emphasize the need to remain vigilant and put safety first. The 7.3-magnitude earthquake that hit Fukushima in 2021 is a reminder of the need to keep our safety focus."

— Rafael Mariano Grossi, Director General, IAEA

(Photos: IAEA)


2011
Fukushima City
2016
Fukushima City
Aizuwakamatsu City

World View

IAEA Updates

Solidarity in safety

Cooperation enhances nuclear safety worldwide

By Joanne Liou

When nuclear or radiological accidents happen, potentially threatening safety and livelihoods, the nuclear community is quick to respond and, longer term, to ensure lessons learned are implemented to strengthen and reinforce safety and prevent future accidents. The initial and ensuing response to the 2011 Fukushima Daiichi nuclear accident — from the local and national to regional and global levels — underscored the essence of this multifaceted response and cooperation found in the nuclear community.

"As we continue to harmonize high levels of national safety, we are contributing to global safety. An incident that occurs at a nuclear installation in one country will impact the rest of the global community."

— Juan Carlos Lentijo, Deputy Director General, Head, Department of Nuclear Safety and Security, IAEA

"International cooperation on nuclear safety is essential for adequate protection of workers, people and the environment, now and in the future," said Borislava Batandjieva-Metcalf, Secretary of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). UNSCEAR, which provides independent scientific evaluations and analyses of the impact of ionizing radiation, is among many partners with whom the IAEA regularly collaborates in the field of safety, as well as in the development of international safety standards.

Responding to Fukushima

In a nuclear power programme, from siting and design to commissioning, operation and emergency preparedness and response, safety is a dynamic practice shaped by standards that are often enforced at the national level. Coordination at the international level is also key.

"Nuclear safety is a national responsibility. Countries take on this responsibility through their institutions, regulators and operators of nuclear technologies and their applications," said Juan Carlos Lentijo, IAEA Deputy Director General and Head of the Department of Nuclear Safety and Security. "International cooperation plays a role in gathering good practices and disseminating this information to allow all countries to be aware of the best practices in nuclear safety."

In the immediate aftermath of the earthquake and tsunami that resulted in the Fukushima Daiichi accident, the IAEA's role became more relevant in real time. "The main goal of the IAEA at that time was to gather information from Japan and disseminate it to the rest of the [international] community to ensure that all Member States were fully aware of what was happening. Simultaneously, the IAEA facilitated international assistance to Japan," Lentijo said.

The international community also enacted coordination mechanisms, such as the Inter-Agency Committee on Radiological and Nuclear Emergencies (IACRNE). Following the 1986 Chornobyl nuclear power plant accident, IACRNE was established to develop, maintain and co-sponsor the Joint Radiation Emergency Management Plan of the International Organizations. The Joint Plan provides the basis for a coordinated and harmonized international response from a range of organizations, such as the World Health Organization, the United Nations Development Programme and the International Criminal Police Organization, INTERPOL.

"During the Fukushima Daiichi nuclear accident, UNSCEAR was involved in the public communications coordination work of IACRNE in order to identify any discrepancies, confusions or inconsistent terminology. New information and measurements have become available in the past years, and UNSCEAR is planning to issue its updated evaluation of the consequences of the Fukushima Daiichi accident this year," Batandjieva-Metcalf said.

Learning from Fukushima

Continuous improvement is a key principle of nuclear safety. About five months after the accident, in September 2011, Member States approved the IAEA Action Plan on Nuclear Safety to strengthen the global nuclear safety framework in 12 areas, including safety assessment of nuclear reactors, IAEA peer reviews, international legal framework and public communication in a nuclear emergency. "The Action Plan was one of the main instruments we put in place to facilitate this gathering and dissemination of lessons and reinforcement of nuclear safety," Lentijo said. "Countries were called upon to reinforce their regulatory infrastructure, as we revisited international safety standards to determine whether they were consistent with what we had learned from the Fukushima Daiichi accident."

One challenge to implementing safety in practice is converting "science and paradigms into international intergovernmental standards that are respected by all States," said Abel J. González, Senior Adviser at the Argentine Nuclear Regulatory Authority and Representative of UNSCEAR. "Under the aegis of the IAEA, a robust international and intergovernmental corpus of safety standards has been established — a unique global normative system for safety."

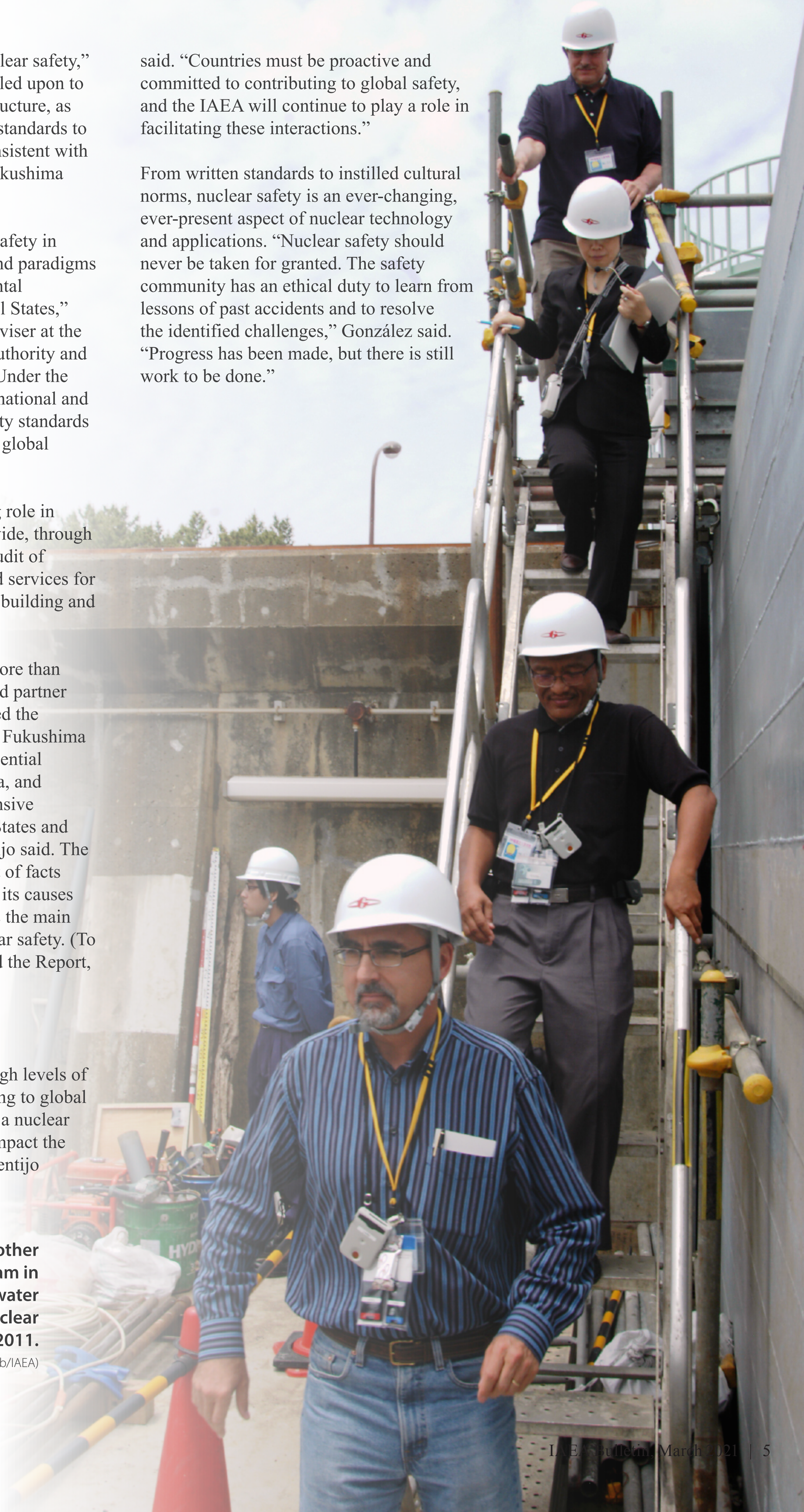
The IAEA has assumed a leading role in promoting nuclear safety worldwide, through the establishment and constant audit of international safety standards and services for Member States, such as capacity building and review missions.

In 2015, with the assistance of more than 180 experts from 42 countries and partner organizations, the IAEA published the Director General's Report on the Fukushima Daiichi Accident. "Japan was essential in providing information and data, and the report is the result of an extensive collaboration with our Member States and other international bodies," Lentijo said. The report is based on the assessment of facts that address the accident — both its causes and consequences — and gathers the main lessons learned to improve nuclear safety. (To read more on the Action Plan and the Report, see page 32.)

Ongoing work

"As we continue to harmonize high levels of national safety, we are contributing to global safety. An incident that occurs at a nuclear installation in one country will impact the rest of the global community," Lentijo said. "Countries must be proactive and committed to contributing to global safety, and the IAEA will continue to play a role in facilitating these interactions."

From written standards to instilled cultural norms, nuclear safety is an ever-changing, ever-present aspect of nuclear technology and applications. "Nuclear safety should never be taken for granted. The safety community has an ethical duty to learn from lessons of past accidents and to resolve the identified challenges," González said. "Progress has been made, but there is still work to be done."



Juan Carlos Lentijo (bottom) and other members of IAEA fact-finding team in Japan descend a ladder at the seawater intake pump area at Tokai Daini Nuclear Power Plant in May 2011.

(Photo: G. Webb/IAEA)

Ensuring the safety of nuclear installations

Lessons learned from the Fukushima Daiichi accident

By Carley Willis

The Fukushima Daiichi nuclear accident reinforced the importance of having adequate national and international safety standards and guidelines in place so that nuclear power and technology remain safe and continue to provide reliable low carbon energy globally.

“The Fukushima Daiichi accident has left a very large footprint on nuclear safety thinking.”

— Greg Rzentkowski, Director, Division of Nuclear Installation Safety, IAEA

By recognizing the lessons learned from the 2011 accident, the IAEA has been revising its global safety standards to ensure that Member States continue to receive up-to-date guidance of high quality.

“The Fukushima Daiichi accident has left a very large footprint on nuclear safety thinking, which manifested itself in a distinct shift from the prevention of design basis accidents to the prevention of severe accidents and, should an accident occur, the practical elimination of its consequences,” said Greg Rzentkowski, Director of the IAEA’s Division of Nuclear Installation Safety.

New safety measures

Following the accident, through a review of relevant standards, including the IAEA safety standard on design safety, experts found that a higher level of safety could be incorporated into existing nuclear power plants by adhering to more demanding requirements for protection against external natural hazards and by enhancing the independence of safety levels so that, even if one layer fails, another layer is unimpacted and stops an accident from happening.

While requirements for protection against natural hazards have always been included in the design of nuclear reactors, these have been strengthened since the accident. In general, the design requirements now take into account natural hazards of an estimated frequency above 1 in 10 000 years, as opposed to 1 in 1000 years used previously.

The defence in depth concept ensures that the various levels of defence in a plant act as independently as possible and thereby provide for effective implementation of safety functions. The need for this independence can particularly be seen in the protection of reactors against common cause events. For example, in the case of a tsunami, back-up safety systems should be located at an elevation sufficiently high to be

protected from potential flooding and ensure their operability when systems designed for normal operation have failed.

Implementing improved safety measures

Incorporating these new safety standards into the design of existing reactors was subsequently tested through comprehensive safety assessments and inspections. The assessments took into account the design features of installations, safety upgrades and provisions for the use of non-permanent equipment to demonstrate that the probability of conditions that may lead to early or large releases is practically eliminated.

“New power plants are designed to account for the possibility of severe accidents,” said Javier Yllera, a senior Nuclear Safety Officer at the IAEA. “Different safety improvements have been implemented at existing power plants, together with accident management measures.”

Safety assessments or ‘stress tests’ implemented in the European Union following the Fukushima Daiichi nuclear accident focused on the assessment of natural hazards such as earthquakes and flooding, and on the behaviour of power plants in cases of extreme natural events and severe accidents. The overall objective was to analyse the robustness of reactors to such events and, if necessary, increase it. The margins of the safety of reactors were analysed and possible improvements were identified. The implementation of those stress tests remained the responsibility of Member States, and resulted in many design and operation enhancements in Europe.

As an example, the French Nuclear Safety Authority (ASN) initiated an assessment of the country’s 56 nuclear power reactors as well as the 2 EPR reactors under construction. The ASN then prescribed the implementation of both fixed and mobile equipment that could potentially prevent a large release, including high-resistance diesel generators and pumps able to function in extreme scenarios such as major earthquakes or flooding. The availability of alternative sources of water for cooling was also prescribed under the same conditions. In addition, the ASN required a back-up plan including rapid action force groups that can be on site within 24 hours with light equipment and within three days with heavy equipment, using transportation means such as helicopters, and that can operate in a severely disrupted environment.

“One of the lessons learned from the Fukushima Daiichi accident is that disruptions caused on and off site by extreme natural hazards can pose major problems,” said Philippe Jamet, former Commissioner of the ASN and Chairman of the Board of the European stress tests. “In the case that an accident does happen, there must be adequate means of transportation to reach the site and trained personnel to work in challenging conditions.”

“In the case that an accident does happen, there must be adequate means of transportation to reach the site and trained personnel to work in challenging conditions.”

— Philippe Jamet, former Commissioner, French Nuclear Safety Authority

Nuclear power plant in Ohi, Japan.

(Photo: Kansai Electric Power Co.)

Ceaseless vigilance

Preparing for and responding to a nuclear or radiological emergency

By Peter Kaiser

> **"Being prepared for the unexpected is vital for developing the agility to respond to increasingly demanding circumstances."**
>
> *— Elena Buglova, Head (2011-2020), Incident and Emergency Centre, IAEA*

The alert came just before sunrise in Vienna on 11 March 2011. The on-call emergency response manager reviewed the seismic report that opened on his laptop screen. Within minutes, staff trained in specialized response roles were called into the IAEA's Incident and Emergency Centre (IEC). He had initiated the IEC's 'full response' for the Fukushima Daiichi nuclear accident, based on the results of an assessment that followed pre-established procedures.

'Full response' means that over 200 staff members trained in regular exercises operate in 12-hour shifts, 24 hours per day, gathering information from emergency contact points in the 'Accident State' — in this case, Japan — and other Member States, dispatching IAEA assistance when requested, informing the international community, while updating the media and public and coordinating the international response.

A mandate to respond

During the intervening quarter of a century between the Chornobyl and Fukushima Daiichi accidents, the IAEA developed these emergency preparedness and response (EPR) 'reflexes', which include procedures, infrastructure, networks and know-how. Progressively during that intervening period, the IAEA expanded its response capacity. Six years before the Tohoku earthquake struck Japan, the IEC opened with a mandate to respond to nuclear and radiological emergencies regardless of whether they are caused by natural disasters, safety failures or malicious intent.

IAEA Specialists staff the IAEA's Incident and Emergency Centre after Japan's nuclear emergency.
(Photo: IAEA)

"The IEC is purpose-built to handle safety or security related emergencies, including extreme events, and to respond effectively regardless of the pressure," said Elena Buglova, Head of the IEC from 2011 to 2020 who led the IEC's response at that time.

Rafael Martinčič, a 20-year IAEA veteran and an expert in EPR, served in the operational area of the IEC during the marathon 1300-hour-long response to the Fukushima Daiichi accident. "For me, the key EPR lesson learned in that response is to emphatically re-emphasize the principle that all countries need to share with each other, and with the IAEA, information on their own protective and other response actions," Martinčič recalled.

Sharing information supports a consistently effective response and enables governments to provide interested stakeholders "a clear and understandable explanation of the technical basis for decisions on protective actions and other response actions, which is crucial in increasing public understanding and acceptance at both the national and international levels," Martinčič said.

Major exercises, such as the world's largest and longest international exercise, the Level 3 Convention Exercise (ConvEx-3), offer a window into countries' ability to share information about their protective actions in the midst of an emergency. "Every exercise clearly shows how far we have come in the past decade and how far we have yet to go in learning this essential lesson," Martinčič said.

A decade of innovation

Without hesitation, Elena Buglova can name what could have been done differently in the IAEA's response to the Fukushima Daiichi accident, "ideally, the IAEA would have received from Member States, well in advance of this severe accident, a mandate beyond just receiving, verifying and exchanging information. We would have been best prepared if we had had an additional, explicit mandate to develop and share the IAEA's assessment of the information, and, as feasible, provide a prognosis for the future progression of the accident."

The IAEA's response role at the time of the Fukushima Daiichi accident did not include providing a prognosis of the potential evolution of an accident or an assessment of the possible consequences. Following the emergency response, Member States acknowledged the benefits of such informed analysis to support their own national safety determinations. The IAEA General Conference granted the IAEA a mandate to provide this assessment and prognosis. "To this day, we continually reach out to Member States to exercise how the IEC will assess an accident in the midst of an emergency response and how this assessment serves to strengthen the effectiveness of that response," Buglova said.

The IAEA also issued new international safety standards and established a dedicated EPR Standards Committee, EPReSC, in 2015. "EPReSC is the global forum that continually focuses attention on EPR, not just in the aftermath of an accident. At EPReSC, the Safety Standards Committee with the largest membership, countries from around the world can share protection policies and methods to be certain that as many countries as possible can strengthen their response in line with internationally recognized best practice," Buglova said. One of EPReSC's benchmark achievements is the adoption of Preparedness and Response for a Nuclear or Radiological Emergency (IAEA Safety Standards Series No. GSR Part 7), the IAEA safety standard with the largest number of co-sponsoring international organizations.

Preparing for tomorrow's emergencies today

As the current COVID-19 pandemic vividly demonstrates, tomorrow's emergencies will likely increase in complexity, characterized by different combinations of triggering factors and response considerations. Being prepared for the unexpected is vital for developing the agility to respond to increasingly demanding circumstances, Buglova said.

"As someone said, 'luck favours the prepared'. We don't see our job quite that drastically, but we do go out of our way to create challenging exercises. Failure is inevitable if you do not plan. But only an exercise will prove the plan's effectiveness," Buglova said.

The IEC and over 200 trained staff registered on the IAEA's Incident and Emergency System prepare daily for that call to respond as swiftly and effectively as possible.

"The key EPR lesson learned in that response is to empathically re-emphasize the principle that all countries need to share with each other, and with the IAEA, information on their own protective and other response actions."

— Rafael Martinčič, EPR expert who responded to the Fukushima Daiichi nuclear accident

Emergency communication

What have we learned since Fukushima?

By Laura Gil

In a nuclear emergency, the communicator's role is almost as crucial as that of the first responder. Providing clear, accurate information amid the alarm and dread that emergencies provoke — when every second counts — can save lives.

So what have emergency communicators learned from the Fukushima Daiichi nuclear accident?

"Our job as communicators is to help the public make informed decisions about their safety and the safety of their loved ones," said Jessica Wieder, Director of radiation information and outreach at the United States Environmental Protection Agency (EPA), whose responsibilities include radiation monitoring. "Radiation emergencies can be scary, so our impulse in the past has been to first calm public anxiety. Now our primary goal is to translate the seriousness of radiological events into informed preparation and action without causing undue panic."

"We have to communicate at all times, be it good or bad news."

— María Laura Duarte, Head, Communications, Nuclear Regulatory Authority, Argentina

Am I safe?

Any situation involving radioactive materials leads to widespread fear, often because, for many, the concept of radiation is unfamiliar and hard to understand. To respond effectively in these situations, communicators must focus on answering a key question raised by those affected: am I safe?

The Fukushima Daiichi nuclear accident made it clear that, to answer this question and reduce public anxiety, communicators need to provide the public with data in a clear format.

"People wanted data. They wanted numbers," Wieder said. "During the Fukushima Daiichi accident, we learned the importance of getting out timely information. When that didn't happen, we saw how quickly we lost trust and how hard it was to regain it."

Before the Fukushima Daiichi accident, only a handful of people had access to EPA's radiation data, which was password-protected. However, within the first two weeks of the accident, EPA removed the password protection measures and made the data available on its public website, where they have been ever since.

Within 24 hours of the accident, the Tokyo Electric Power Company (TEPCO) — the Japanese company operating the plant

Journalists attend daily briefing on the Fukushima Daiichi accident at IAEA Headquarters in Vienna, Austria, 17 March 2011.
(Photo: D. Calma/IAEA)

in Fukushima — was already providing preliminary radiation monitoring data and real-time updates on conditions at the reactor. It became a challenge, however, for citizens and the media to understand what this information actually meant.

Facts alone do not overcome strong emotions, Wieder added. "We cannot just give the public data; we have to give them data along with explanations, so that they can understand what these data mean in terms of their health."

Since the accident, the IAEA has supported the Fukushima Prefecture in many areas by providing technical expertise and helping disseminate information to the public. It has helped produce relevant public information materials, including flyers and a website, that show the results of radiation monitoring and decontamination efforts. "Using pictures, infographics, clear explanations and language free of scientific jargon is key to achieving public understanding of the data and addressing perceived risks," said Miklos Gaspar of the IAEA's Office of Public Information and Communication and technical officer who oversees the information dissemination support to the Fukushima Prefecture.

Many voices, one message

Once built, credibility must be maintained. In the aftermath of the Fukushima Daiichi accident, communicators learned that, to maintain the public's trust, authoritative voices in an emergency must use the same message with the same tone of voice. "If one organization says one thing, and one expert another, we've lost trust. We can't afford that in emergencies," Wieder said.

When various trusted sources send out the same data and the same messages to the public, it works. "Having somebody external echoing your message brings a level of additional reliability to the information you are putting out that you might not otherwise have by yourself," said María Laura Duarte, Head of Communications at Argentina's Nuclear Regulatory Authority. "Coordinating that in advance is critical."

In Argentina, like in many other countries, Government representatives, responders and experts from academia have joined forces to work on emergency communication, forming networks, so that in the event of an emergency they know exactly who to call. Involving and briefing the media in advance in preparation for possible incidents, and including them in response exercises, is also useful, Duarte said.

A lie can travel halfway around the world while the truth is still putting on its shoes

In addition to building trust, coordinated and consistent messaging helps combat misinformation. Following the Fukushima Daiichi accident, information shared by citizens was sometimes incorrect. "The perceived risk of radiation is very high," Wieder said. "And that leads to misinformation."

While it is next to impossible to respond to every rumour, communicators agree that the key is to focus on those that are most widespread, and to step in with several different partner organizations to root out inaccuracy.

"If you have to deal with misinformation, try to find a partner who is trusted, for example a doctor from a hospital, and let them clarify the situation to support your message," said Cora Blankendaal, Senior Communications Advisor at the Nuclear Research and Consultancy Group (NRG), a company that operates a nuclear research reactor in the Netherlands.

Building trust, one day at a time

But building trust is not only important during emergencies.

"We have to communicate at all times, be it good or bad news," Duarte said. Educating the population and communicating with them daily, in an open and transparent manner, will make them more prone to trusting the authorities' messages — should an emergency occur. Social media has become an effective way to do this, since it allows communicators and the public to engage in two-way interactions and build a public dialogue, she said.

Earning public trust means "engaging representatives of the community in radiation measurement and communicating with the public continuously and transparently," said Gaspar.

"During the Fukushima Daiichi accident, we learned the importance of getting out timely information. When that didn't happen, we saw how quickly we lost trust and how hard it was to regain it."

— Jessica Wieder, Director, Communications, United States Environmental Protection Agency (EPA)

Know the IAEA Safety Standards

By Michael Amdi Madsen

What are the IAEA safety standards?

Nuclear technologies hugely benefit society, whether it's producing low carbon energy, treating cancer, sterilizing food or monitoring soil erosion. Applying these technologies, however, requires careful regulation to reduce risks and prevent potential radiation exposure of workers, patients, the public and the environment. This is where safety standards enter the picture.

While the prime responsibility for safety lies with the person or organization responsible for activities involving nuclear technology, regulating safety is a national responsibility, and the IAEA can help. The IAEA produces safety standards that reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation.

The IAEA safety standards cover all nuclear and radiation applications utilized for peaceful purposes, and provide guidance and requirements for the medical uses of radiation, the operation of nuclear facilities (such as nuclear power plants), the production, transport and use of radioactive material, and the management of radioactive waste.

How are they structured and developed?

The IAEA safety standards consist of three sets of publications: Safety Fundamentals, which establish the fundamental safety objectives and the principles of protection and safety in language that's understandable to non-expert readers; Safety Requirements, which set out the requirements that must be met to ensure the protection of people and the environment, both now and in the future,

and help countries establish their national regulatory frameworks; and Safety Guides, which present good and best practices and offer recommendations and guidance on how to comply with the Safety Requirements.

Creating the IAEA safety standards is an open and transparent process in which knowledge is gathered, synthesized and integrated from experience of using nuclear technologies around the world. Drafts produced by the IAEA Secretariat are then reviewed by five different Safety Standards Committees and shared with IAEA Member States for comments and further input.

The Committees cover nuclear safety, radiation safety, safety of radioactive waste, the safe transport of radioactive material, and emergency preparedness and response, and include nominated experts and officials from different countries and organizations. All IAEA safety standards are endorsed by the Commission on Safety Standards, and the Safety Fundamentals and Safety Requirements are also ultimately approved by the Board of Governors — one of the IAEA's governing bodies.

How are they applied?

Applying IAEA safety standards is a decision made by countries. The IAEA safety standards are not legally binding on countries, and Member States apply them at their own discretion. The standards do apply, however, to the IAEA in its own operations and when the Agency provides assistance to countries.

When a country chooses to apply IAEA safety standards, it often looks to adopt them for use in its own national regulations. The IAEA safety standards are also sometimes applied by other organizations or industries that design, construct and operate nuclear facilities, or use radiation and radioactive sources.

The BN-800 commercial fast reactor at the Beloyarsk Nuclear Power Plant in Russia.

(Photo: Rosenergoatom)

Fukushima Daiichi: The accident

By Laura Gil

More than one factor alone led to the accident that took place at Fukushima Daiichi on 11 March 2011.

First factor: Earthquake and tsunami

As the 9.0 magnitude earthquake hit the Japanese shore, the reactors of the Fukushima Daiichi nuclear power plant shut down automatically to control the nuclear fission. The electrical lines collapsed, but the plant responded as designed, and the earthquake itself did not cause any other problems. The tsunami it triggered, however, did.

“The reactors were robust, seismically speaking,” said Gustavo Caruso, Director of the IAEA’s Office of Safety and Security Coordination. “But they were vulnerable to the high tsunami waves.”

When the flooding hit, the ‘tsunami walls’ made to protect the plant from such events were too low to prevent the sea water from entering the plant. The water’s strength destroyed some of the structures, and entered the diesel generator room — which was built lower and at a closer distance to sea level than other plants in Japan — affecting Units 1, 2 and 3.

“In spite of all the efforts that were made, and in spite of the nuclear power plant structure resisting the earthquake, the tsunami was the main cause that affected the plant’s defence in depth design, bypassing several safety layers and leading to core melts in Units 1, 2 and 3,” Caruso said.

Second factor: Design weaknesses

“The diesel generators are essential for maintaining the plant’s electrical supplies in emergency situations,” said Pal Vincze, Head of the Nuclear Power Engineering Section at the IAEA. “They were drowned.”

If the diesel generator is affected, special batteries can be used to generate electricity, but these have a limited capacity, and, in the case of Fukushima Daiichi, some were also flooded. “In Japan, they put up a heroic fight to get the electrical systems up and running again, but it wasn’t enough,” Vincze added.

Without functioning instrumentation and control systems, or electrical power or cooling capabilities, the overheated fuel melted, sank to the bottom of the reactors, and breached the reactor vessels, leading to three meltdowns. In addition, data logs and

vital systems operated by safety parameters were also flooded, which meant that there was no way for the operator to monitor what was going on inside the reactors.

Third factor: Shortcomings in safety culture

As stated in the IAEA report on the Fukushima Daiichi accident, “a major factor that contributed to the accident was the widespread assumption in Japan that its nuclear power plants were so safe that an accident of this magnitude was simply unthinkable. This assumption was accepted by nuclear power plant operators and was not challenged by regulators or by the Government. As a result, Japan was not sufficiently prepared for a severe nuclear accident in March 2011.”

This complacency amounted to a ‘basic assumption’ that the plant could cope with anything, whether it was related to technology or nature. When planning, designing and constructing the plant, experts did not properly take into consideration past tsunami experiences.

“There was a belief that the plants were safe enough, and that they were fully prepared to face extreme external events,” Caruso said. “It must be noted that the combination of an earthquake of this magnitude and a tsunami is extremely rare, but unfortunately this is what happened.”

This basic assumption, combined with a lack of adequate training among operators in accident management and a lack of sufficient compensatory measures against tsunamis, are what led to the accident, Caruso added.

Fourth factor: Gaps in the regulatory system

The Fukushima Daiichi accident exposed certain weaknesses in Japan’s regulatory framework. According to the Report, responsibilities had been divided among a number of bodies, and it had not always been clear where authority lay. The Report also points out that some of the IAEA safety recommendations made to the regulator had not been implemented, and some international standards had not been met.

It must be said, Caruso concluded, that in spite of the core damage that led to the release of radioactive material into the environment, no health effects could be attributable to radiation, because “based on dose data, and environmental and personal monitoring, the effective doses incurred by members of the public were very low and generally comparable with the range of effective doses incurred due to global levels of natural background radiation.”

Sampling boat close to Fukushima Daiichi nuclear power plant.
(Photo: NRA)

Recovering from a nuclear emergency

How Fukushima did it

By Laura Gil

> **"Dose rates have fallen significantly since the accident due to natural decay of the radioisotopes and decontamination activities, but it is not easy to clean up all the radioactive contamination."**
>
> *— Minako Kamota, expert who has worked on environment-related reconstruction work at Fukushima Prefecture since 2011*

Less than an hour. That's the time it took the earthquake-triggered tsunami of 2011 to reach Japan's eastern shoreline. Soon after, the first tsunami hit the Fukushima Daiichi nuclear power plant, leading to an accident that forced tens of thousands of people to evacuate. Since then, the Government of Japan and the authorities of Fukushima Prefecture have made significant efforts to make much of the evacuated areas inhabitable again. A decade after the accident, what does life look like in the affected areas of Fukushima Prefecture?

"Japan's efforts to clean up residual radioactive contamination have been enormous," said Miroslav Pinak, Head of the IAEA's Radiation Safety and Monitoring Section and team leader of an IAEA project to support the Fukushima Prefecture in the recovery work. "Since 2012, the IAEA has been providing assistance to the Prefecture in that and other activities, including radiation monitoring, and analyzing and communicating the results effectively. Children are now playing in school playgrounds and hikers are using the forests of Fukushima Prefecture where access was restricted following the accident, and we see this as a definite success."

The IAEA has provided technical expertise, equipment, expert missions and guidance on recovery operations — based on international examples and the IAEA safety standards (for more on safety standards, see page 12). It has been supporting Japanese authorities and scientists in three technical areas: radiation monitoring, remediation and the management of waste from decontamination activities.

Radiation monitoring is important when dealing with a nuclear or radiological emergency. Experts need to answer key questions. Has there been a release of radioactive material? If so, what types and amounts of radionuclides have been released? How can people and the environment be protected in the most effective way? To answer such questions, radiation levels in the environment need to be measured frequently during an emergency.

"During an emergency, radiation monitoring assists in determining whether protective actions, such as sheltering or evacuation, are implemented precisely where these actions are needed and when they are needed," said Florian Baciu, Acting Head of the IAEA's Incident and Emergency Centre.

Significant amounts of radioactive isotopes of caesium, or radiocaesium, were released into the air and deposited in the forests, soils and bodies of water of the Prefecture. With IAEA help, Japanese authorities have established long-term monitoring programmes to detect radiocaesium on land and in water, in addition to measuring radioactivity in wild animals, mushrooms and other food from the forests.

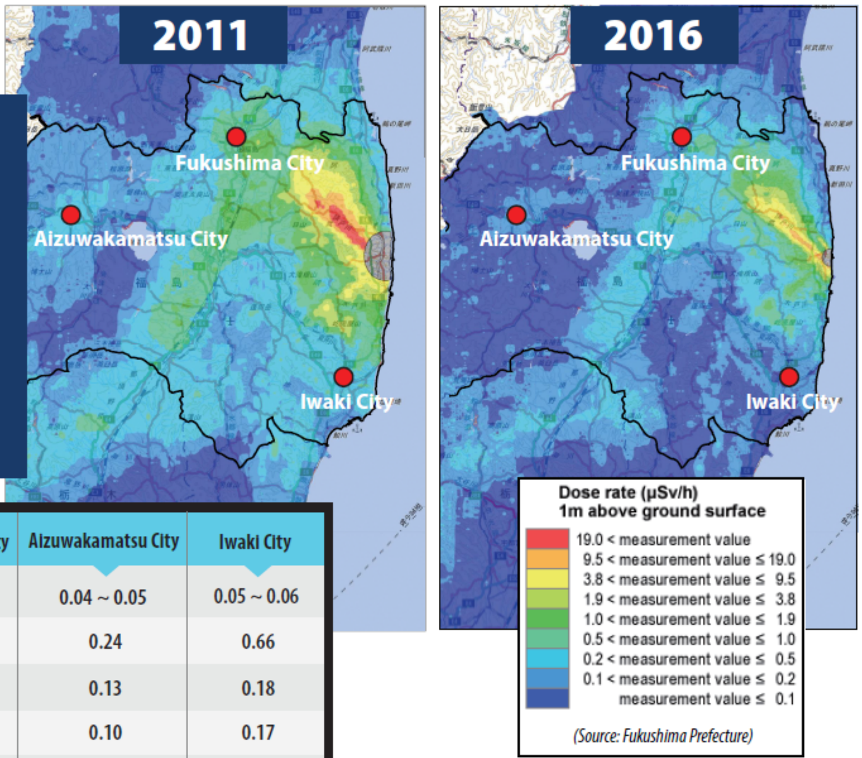
Because of natural radioactive decay, it is expected that the radiation level will gradually decrease, Pinak added. "According to the results of the long-term monitoring programme in forests, the air dose rate overall decreased by about 78% between 2011 and 2019. As time progresses, radioactivity concentrations in forests will continue to decrease and monitoring programmes will reflect that tendency."

Nature lends a hand

What experts observed, after years of monitoring and analyzing results, is that most of the radiocaesium was retained within the forest — and was not circulating in the air. In other words, nature, in addition to the chemical and physical properties of radionuclides, has been helping contain radioactive contamination and keep it away from people.

"A person can be exposed to radiocaesium through both external and internal exposure. Internal exposure, through ingestion or inhalation, can lead the element to concentrate in the soft tissues of the body, especially muscle tissue," Pinak said. "That is why it is good news that the clay minerals in the forest soil bind radiocaesium, preventing its transfer to vegetation and agricultural land."

Comparison of air dose rates in 2011 & 2016



All data in µSv per hour	Fukushima City	Aizuwakamatsu City	Iwaki City
Before March, 2011	0.04	0.04 ~ 0.05	0.05 ~ 0.06
April, 2011	2.74	0.24	0.66
September, 2011	1.04	0.13	0.18
March, 2012	0.63	0.10	0.17
March, 2013	0.46	0.07	0.09
March, 2015	0.23	0.06	0.07
March, 2017	0.17	0.05	0.07

Source: Fukushima Prefecture Disaster Response Headquarters (provisional values)

The air dose rates in major cities of Fukushima Prefecture have decreased to similar levels as measured elsewhere in the world.

Radiation monitoring stations dot the countryside of the Fukushima Prefecture, where life is steadily going back to normal.
(Image: F. Nassif/IAEA and Fukushima Prefecture)

The rivers, ponds and lakes of the Prefecture that surround the power plant zone have also played their part. In freshwater ecosystems, radiocaesium binds to suspended sediments, which deposit on the bottom of the waterbody. This causes a rapid decline of dissolved radiocaesium levels in the water.

Remediation and decontamination

Even though nature played its part and the physical process of radioactive decay led to a significant decrease in individual radionuclide activity, additional effort was needed to clean up radioactive contamination in various areas. Since the accident, the Prefecture has been implementing remediation activities by, for instance, scraping the contaminated top layer of the soil, and has been safely managing the resulting radioactive waste.

“The waste that is generated in the Prefecture is collected and stored at temporary storage sites, which are either on site or nearby,” Pinak said. “This waste is being placed in the Interim Storage Facility (ISF), which is being developed and operated by the central Government. After interim storage in the ISF for up to 30 years, final disposal will take place outside the Prefecture.”

There are still many challenges arising from the accident, with radiation monitoring stations dotting the countryside. However, life in most of the Prefecture is steadily returning to normal.

“Dose rates have fallen significantly since the accident due to natural decay of the radioisotopes and decontamination activities, but it is not easy to clean up all the radioactive contamination,” said Minako Kamota, who has worked on environment-related reconstruction work at Fukushima Prefecture since 2011. “Some of the surrounding areas are still classified as Difficult-to-Return Zones, but the environment in most other regions has been remediated close to the state before the accident.”

“Japan’s efforts to clean up residual radioactive contamination have been enormous.”

— Miroslav Pinak, Head, Radiation Safety and Monitoring Section, IAEA

Safety by design

How the new generation of nuclear reactors addresses safety

By Joanne Liou

Beneath the stands of the University of Chicago's athletic field, the first self-sustaining nuclear chain reaction transpired in 1942. In a wooden frame, graphite blocks interspersed with uranium comprised the 'pile' — the nuclear reactor. Above, a control rod hung on a rope, and a man wearing protective clothing stood by, ready to chop the rope with an axe if anything were to fail. The rods would fall into the reactor core, shutting down the chain reaction. The man personified the world's first nuclear safety system.

> **"The major safety challenge present in the existing nuclear fleet centres around the ability to remove residual (decay) heat and keep the reactor cool."**
>
> *—Carrie Fosaaen, Director, Regulatory Affairs, NuScale Power*

In the succeeding decades, safety has influenced the evolution of reactors, from prototypes in the 1950s and commercialized power reactors in the 1960s to advanced designs that appeared in the 1990s. A far reach from that original axe man, today's reactors feature designs and systems that ensure a high level of safety.

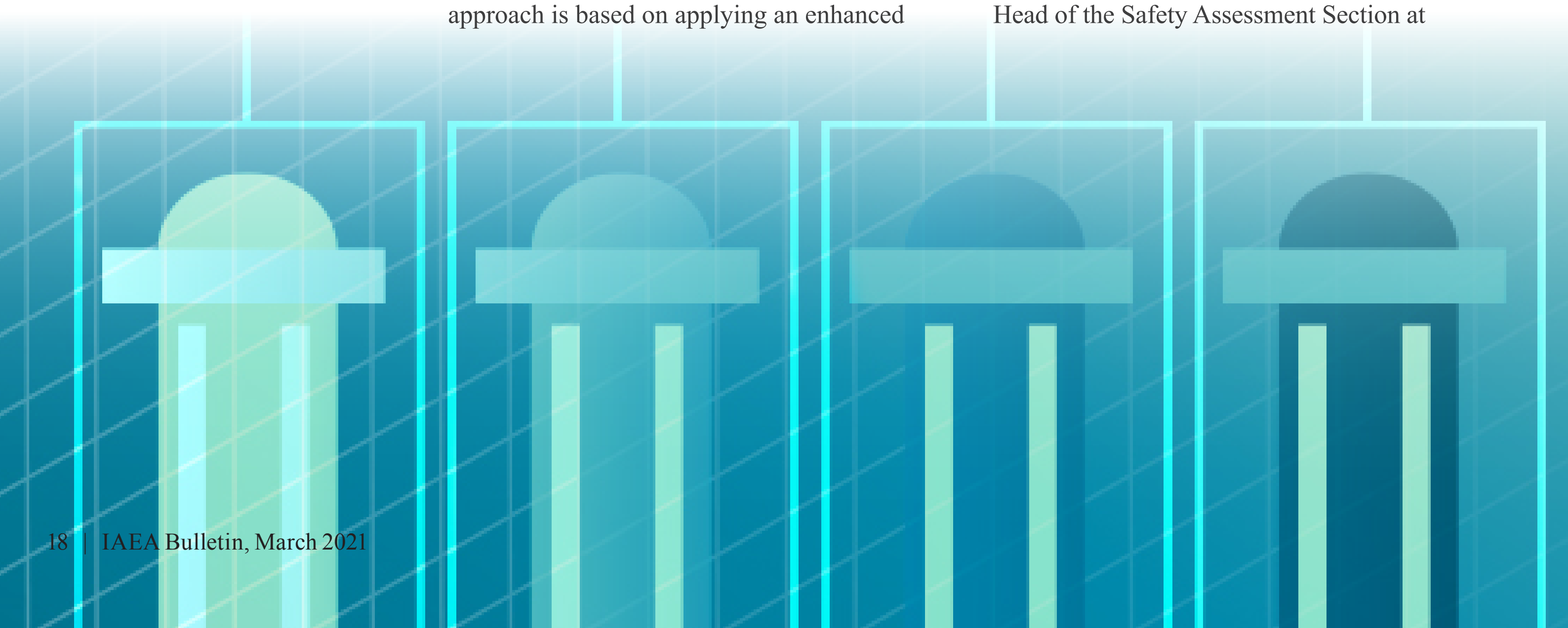
The new generation of nuclear reactors includes some reactors already in operation and reactor designs that have yet to be deployed. The IAEA distinguishes advanced nuclear reactors as evolutionary or innovative, both of which incorporate lessons learned from the 2011 Fukushima Daiichi nuclear accident. Evolutionary reactors improve existing designs, maintaining proven design features, while innovative reactors use new technology.

Most evolutionary reactors are available on the market and are already connected to the grid. These reactors' underlying safety approach is based on applying an enhanced defence-in-depth strategy, compared to conventional reactors, supported by increasing emphasis on inherent safety characteristics and passive features and decreasing reliance on the operator's intervention to minimize the risk of accidents.

Innovative reactors incorporate radical changes in the use of coolants, fuels, operating environments and system configurations. Some innovative concepts are being considered for deployment in the next 10 to 20 years.

"From the technology viewpoint, [innovative reactors] are very different because, typically, they do not use water as a coolant," said Stefano Monti, Head of the Nuclear Power Technology Development Section at the IAEA. From the physical viewpoint, he added, the different coolant also changes the way in which heat is extracted and the way in which the nuclear fission reaction is produced and maintained.

Advanced fast neutron reactors that are sodium, lead and lead–bismuth or gas cooled, for example, use much higher-energy neutrons to cause fission. Fast neutron reactors are designed to improve fuel efficiency and therefore reduce high level radioactive waste. "From the safety perspective, the risks associated with their operation are very low, owing to the reduction in both the likelihood and the radiological consequences of accidents," said Vesselina Ranguelova, Head of the Safety Assessment Section at



the IAEA. The IAEA's Advanced Reactors Information System provides detailed technical and safety information for all these types of advanced reactors.

The world's first advanced small modular reactors (SMRs) were deployed last year in Russia, and many innovative SMRs are under development for near-term deployment. Globally, there are about 70 SMR concepts and designs, with two at advanced stages of construction in Argentina and China.

Safety systems

Lessons learned from the Fukushima accident led to significant strengthening of international safety requirements, which are to be reflected in the design of advanced reactors so that the likelihood of occurrence of an accident with serious radiological consequences is extremely low and the radiological consequences, should an accident occur, are practically eliminated. (To learn more about the Fukushima Daiichi accident, see page 14.)

The proof of concept for SMRs requires the vendors to demonstrate the effectiveness of the fundamental safety functions — reactors control, core cooling and confinement of reactivity — based on the development and evaluation of the defence-in-depth strategies.

As an example, US-based NuScale Power has designed a modular light water reactor that integrates components for steam generation and heat exchange into a single unit, expected to be deployed in 2027. "The major safety challenge present in the existing nuclear fleet centres around the ability to remove residual (decay) heat and keep the reactor cool," said Carrie Fosaaen, Director of Regulatory Affairs at NuScale Power. "The overall design of the NuScale power plant incorporates simpler systems, which preclude the need for the complex configurations currently required in existing nuclear facilities."

Given the nature of innovation, the introduction of passive and other innovative safety features poses a regulatory challenge. Regulators are tasked with verifying designers' claims of safety, which may require additional research and analysis to evaluate novel designs.

"To demonstrate design safety, a comprehensive assessment of all plant states — normal operation, anticipated operational occurrences and accident conditions — is required. On that basis, the capability of the design to withstand internal and external events can be established and the effectiveness of safety features can be demonstrated." Ranguelova said. "While the innovative designs are promising, they must be complemented with a regulatory body's sound safety assessment and licensing process that supports their utilization and deployment."

"While the innovative designs are promising, they must be complemented with a regulatory body's sound safety assessment and licensing process that supports their utilization and deployment."

— Vesselina Ranguelova, Head, Safety Assessment Section, IAEA

Technology-neutral framework for safety

The IAEA is assessing the level to which existing IAEA safety standards can be applied to innovative technologies. "Our safety standards are technology-neutral. However, they have mostly been developed using the operational experience of reactors, which are mostly water cooled reactors," Ranguelova added. Though the standards are neutral in principle, implementation may differ for some or all types of SMRs.

"There are gaps where we will need to develop additional guidance or supporting documents to allow for the application of these standards to innovative technologies," Ranguelova said. The IAEA expects to publish a Safety Report on the applicability of IAEA safety standards to SMR technologies in 2022.

Image: K. Vargas/IAEA

Spurring youth interest in nuclear
The challenge for safety

By Sinead Harvey

As nuclear technology plays a significant role in energy generation, efforts to ensure the long-term sustainability of nuclear safety are crucial. Recently, young people in many countries have been turning away from careers in nuclear. With nuclear safety relying on a robust transfer of knowledge to new generations, how can the international nuclear community attract young people to careers in nuclear in general and nuclear safety in particular?

"Diversity makes the entire nuclear sector more flexible and dynamic, and, at the end of the day, more successful."

— John Lindberg, PhD student, King's College London and Imperial College London, United Kingdom

"To adapt to a changing world, we have to infuse the nuclear sector with new energy and new perspectives, and ensure it is attracting the best and brightest," said Rumina Velshi, President of the Canadian Nuclear Safety Commission (CNSC). Velshi understands that national regulators such as the CNSC have a duty to attract and retain young people to nuclear careers in order to ensure the highest levels of safety. "When we exclude — or fail to open ourselves up to — part of the population, we fall short of our potential," said Velshi.

Young people and nuclear

A hiatus in the building of new reactors, particularly in the West, coupled with political discourse against nuclear energy, has led to a global decline in the number of young people studying towards careers in the sector. In the 2021 Global Energy Talent Index report, which surveyed people working in the nuclear sector across 166 countries, 29% of respondents were between the ages of 18 and 34, compared to 36% who were over 55.

John Lindberg has spent the past few years working towards a PhD on the long-term impact of the negative perception of nuclear power at King's College London and Imperial College London in the United Kingdom. "The problem is that some people perceive nuclear technologies as something of the past and something to be feared," he said.

This is highlighted in a recent survey by the Institute of Mechanical Engineers, which found that, among young people, there is a general scepticism towards nuclear power and an unawareness of its role as a low carbon source of energy. According to the survey, young people are concerned about the safety of nuclear energy, especially when it comes to the management of nuclear waste.

Lindberg argues for proper education in this area. "It is crucial that the international community and the global industry work together to engage with students to not only help dispel these notions, but, more importantly, help build well-deserved enthusiasm for nuclear technologies, and the many career opportunities that the sector offers."

Changing youth perceptions

Jawaher Al-Tuweity is a PhD candidate researcher in ionization radiation metrology,

(Photo: D. Calma/IAEA)

medical physics and radiation protection at the Ibn Tofail University in Kenitra, Morocco. As general coordinator of the Yemeni Forum for Scientific Research and Sustainable Development and leader of the Yemeni Young Professional Network (YYPN), she has worked for years to build up opportunities for young people in nuclear technologies in her native Yemen.

"It is essential that the industry cooperate with the education sector to share information and opportunities for young people to discover their scientific talents and fields of interest and to change their perception of nuclear," Al-Tuweity said. The issue for Yemen, and many other developing countries, is one of inequality. "The efforts being made are not sufficient and not sustainable, as they are not benefiting developed and developing countries equally."

Diversifying the nuclear workforce drives innovation in the sector as a whole, Al-Tuweity added. Some global efforts have been made to level the playing field. The IAEA Marie Skłodowska-Curie Fellowship Programme, for instance, targets financial support to women studying nuclear subjects at the graduate level. Fellowships have so far been awarded to 100 students from 71 countries.

PhD student Lindberg also advocates for the diversification of the industry. "Diversity makes the entire nuclear sector more flexible and dynamic, and, at the end of the day, more successful. It helps us to avoid the well-known dangers of groupthink and of getting stuck in 'echo chambers', where groups only hear the same perspectives and opinions repeatedly," he said. "Public engagement is one area, where additional diversity of thought is crucial, as it would encourage new and innovative methods for engaging with the public on the benefits of nuclear energy."

Career paths

To avoid repeating safety issues from the past, companies can invest now to ensure the proper transfer of knowledge. Networking and mentorship programmes play a dual role in transferring knowledge and offering the career progression young people want when entering a job.

The IAEA's International Conference on Radiation Safety: Improving Radiation Protection in Practice, held in November 2020, included a Professional Development Programme that offered interactions between nuclear industry veterans and young people to bring new ideas to the table and give momentum to and ensure the sustainability of the industry.

The CNSC also uses the diverse range of careers available within nuclear safety as a way to entice young people. "We are expanding efforts to talk about nuclear safety beyond audiences that are nuclear engineering students or communities with a nuclear facility," Velshi said. "I recently gave a talk to graduate students in geotechnical engineering and there was a major interest among students about public trust and nuclear, and their role as engineers in this area."

Climate change and the digital revolution

Across the world, young people have driven the protests for action against climate change, the biggest global challenge faced today. These young people are educated about climate-related issues and are eager to participate in the global discussion about the future of the planet. Climate change mitigation remains a key driver for maintaining and expanding the use of nuclear power, and the latest IAEA annual projections show that global nuclear electrical capacity could double by 2050. This is an opportunity for the nuclear industry and the international community to present nuclear and nuclear safety as an exciting and relevant career choice in a growing and innovative field.

With a comprehensive education in nuclear, an understanding of its benefits for people and the environment, career progression opportunities and the comprehensive diversification of its workforce, nuclear can become a coveted career.

For Velshi and the CNSC, the digital revolution in nuclear safety represents an opportunity for young people. "Today we are at the start of the 'fourth industrial revolution' — or the digital revolution. This new chapter in human development, driven primarily by scientific and technology advances is evolving at an exponential rate. This applies to the nuclear sector as well. We know that the nuclear industry is looking to find innovative solutions, from robotics to quantum computing, to using artificial intelligence to address existing challenges. A career in nuclear safety offers you the possibility to be at the forefront of this revolution."

"When we exclude — or fail to open ourselves up to — part of the population, we fall short of our potential."

— Rumina Velshi, President, Canadian Nuclear Safety Commission (CNSC)

IAEA's safety leadership school promotes a strong safety culture

By Anjarika Strohal

Why is leadership vital in nuclear safety? Leadership is needed to initiate appropriate safety actions, motivate staff to ensure safety procedures are followed 24/7, and provide guidance on implementing safety measures.

Learning about the importance of leaders in safety is part of the IAEA International School of Nuclear and Radiological Leadership for Safety, launched in 2016.

Cultivating a safety culture among staff, so that they can understand the importance of safety and the measures required to sustain it, is key in the nuclear industry. Establishing a strong safety culture is one the most fundamental management principles when using nuclear technology. It aims to strengthen the implementation of a systemic approach to safety, that is, the interaction between humans, technology and organizations within the national nuclear infrastructure. The importance of safety culture is one of the key lessons learned from the Fukushima Daiichi nuclear accident.

"The goal of the School is to enable current leaders and future ones in the nuclear field to have a better and more insightful understanding of their role in having a robust safety culture at nuclear facilities around the world," said Shahid Mallick, Head of the Programme and Strategy Coordination Section of the IAEA's Office of Safety and Security Coordination. "Communicating policies and plans on the safety-first principle is important when using nuclear technology."

The School focuses on the application of nuclear and radiological safety leadership concepts to real-life situations. It aims to develop the leadership skills of mid-career professionals and uses normal and emergency scenarios to test leadership and management skills. "The high demand in attending the School from across our Member States since its introduction is a reflection of the requirement for such support," Mallick said.

Safety: top-down and bottom-up

Participants in the School learn new ways to communicate through a pedagogic progression of learning objectives, starting from 'goals', 'values and attitudes' and 'engagement', and leading to the understanding of more complex, real-life situations illustrated by case studies, presentations, key note addresses and

discussions. The syllabus provides them with a fundamental basis and understanding of safety as a top priority. The curriculum is developed by experts from international organizations, nuclear operators and academia, and includes hands-on training based on case studies on nuclear or radiological emergencies.

Karmolporn Pakdee, a dissemination officer at Thailand's Office of Atoms for Peace who attended the first IAEA International School of Nuclear and Radiological Leadership for Safety hosted by Tokai University, Japan, in February 2020, said: "Nuclear and radiological safety needs everybody's cooperation. We all need to be committed to it as a team, through planning and systematic approaches that include the proper use of diverse tools and communication — only then can we bring nuclear and radiological safety to the public in every corner of the world."

Through case studies and leadership games, participants address situations such as an unintended medical exposure, nuclear power plant outages and radioactive material leaks. They are asked to identify gaps and ways to help an organization improve its nuclear safety processes and mechanisms.

One of the areas underlined in The Fukushima Daiichi Accident, a 2015 report by the Director General, was the need for a systemic approach to nuclear safety. Practical exercises conducted at the School test this approach in simulated scenarios inspired by real-life situations, said María Moracho Ramírez, a Senior Safety Officer at the IAEA, adding that "regardless of their position and role in an organization, staff at all levels must demonstrate commitment and leadership for safety."

Rosbell Bosch Robaina, President of the Ibero-American Forum of Radiological and Nuclear Regulatory Agencies (FORO), said that "the School was a unique experience, as well as my best learning experience. It provided all of us with many tools to effectively address leadership for safety and an international perspective through the sharing of knowledge with peers and proven senior nuclear leadership experts. Being part of a new network group also allows us to share knowledge and experiences."

The IAEA continues to support Member States in fostering a safety culture and developing leadership skills to ensure the safe management of nuclear facilities. A pilot version of the School was held in France in 2017. The successful methodology was extended to India and Mexico in 2018, followed by courses in Brazil, Morocco, Pakistan and Turkey in 2019, and Japan in 2020. The curriculum is normally foreseen to be face-to-face in order to achieve the most effective results; nonetheless, a hybrid version of the School that will include virtual elements is being developed as a complementary online learning approach, in response to Member States' requests.

"Nuclear and radiological safety needs everybody's cooperation. We all need to be committed to it as a team […] — only then can we bring nuclear and radiological safety to the public in every corner of the world."

— Karmolporn Pakdee, dissemination officer, Office of Atoms for Peace, Thailand

International legal instruments corroborate liability, safety regimes

By Joanne Liou

During normal operations and particularly in the event of the unexpected, an adequate legal framework for the safe, secure and peaceful use of nuclear technology is indispensable. The national and international nuclear legal systems of today provide a legal framework for conducting activities related to nuclear energy and ionizing radiation in a manner that adequately protects individuals, property and the environment, and helps determine liability when something goes wrong.

The 1986 Chornobyl accident prompted the swift adoption of the Convention on Early Notification of a Nuclear Accident (Early Notification Convention) and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (Assistance Convention), which form the legal basis for the international emergency preparedness and response framework. Further negotiations led to the adoption of the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention in 1988, as well as the Protocol to Amend the Vienna Convention on Civil Liability for Nuclear Damage and the Convention on Supplementary Compensation for Nuclear Damage in 1997. In addition, the 2011 Fukushima Daiichi nuclear accident catalyzed efforts to further strengthen the existing framework for nuclear liability and safety.

"At the time of the Chornobyl accident in 1986, there were few treaties that had been concluded under the auspices of the IAEA in relation to the peaceful uses of nuclear energy," said Andrea Gioia, Senior Legal Officer at the IAEA. In addition to the adoption of the 1986 Early Notification and Assistance Conventions, the Convention on Nuclear Safety (CNS) was later adopted in 1994, followed by the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management in 1997.

Following the Fukushima Daiichi nuclear accident, Member States adopted the IAEA Action Plan on Nuclear Safety (read more on page 32), in which one of the 12 areas outlined focused on reinforcing the international legal framework. "The main emphasis here was placed on the effective implementation of the existing treaties, as well as on the strengthening of the nuclear liability regime," Gioia said.

Facilitating global nuclear liability

The significance of a global nuclear liability regime to delineate legal responsibilities

Convention on Nuclear Safety

One of the objectives of the Convention on Nuclear Safety (CNS), which entered into force on 24 October 1996, is "to achieve and maintain a high level of nuclear safety worldwide through the enhancement of national measures and international cooperation." The obligations for the 90 Contracting Parties under the CNS include submitting National Reports on the implementation of their obligations under the CNS for "peer review" in meetings held every three years.

"lies in two major areas: public confidence and nuclear trade. If nuclear power is to play its necessary part in the decarbonization of world energy supply, it is critical that barriers to the development of new facilities, such as uncertainty around liability arrangements, are removed," said Steven McIntosh, Chairman of the International Expert Group on Nuclear Liability (INLEX).

The IAEA Action Plan sets out the need to establish "a global nuclear liability regime that addresses the concerns of all States that might be affected by a nuclear accident, with a view to providing appropriate and sufficient compensation for nuclear damage," McIntosh, who is also Senior Manager of Government and International Affairs at the Australian Nuclear Science and Technology Organisation (ANSTO), said.

Though the Convention on Supplementary Compensation for Nuclear Damage (CSC) was adopted in 1997, it was not until 2015 that it entered into force when Japan submitted its instrument of acceptance.

"Contracting Parties have decided to create a system of regular meetings to examine problems of common interest and to further promote adherence to the CSC, strengthening global liability," Gioia said.

The first meeting of the CSC parties took place in 2018, and the next meeting is expected to convene in August 2021 in Vienna. The CSC aims to increase the amount of compensation available in the event of a nuclear accident through public funds to be made available by the Contracting Parties at the United Nations rate of assessment.

Upholding the Convention on Nuclear Safety

While attempts to amend the CNS following the Fukushima Daiichi accident were unsuccessful, a political declaration — the Vienna Declaration on Nuclear Safety (VDNS) — was adopted by consensus in 2015. The VDNS guides Contracting Parties in the design, siting and construction of new nuclear power plants and contains guidance on periodic safety assessments of existing installations to identify safety improvements to meet CNS objectives. "Contracting Parties also committed themselves to reflect these principles in their actions when preparing their Reports to be submitted for consideration of the 7th Review Meeting of the CNS in 2017," said Judit Silye, IAEA Legal Officer.

Furthermore, the Working Group on Effectiveness and Transparency was established to provide guidance on meeting CNS objectives, as well as to support the preparation of National Reports and improve transparency, the review process and international cooperation. "In this regard, each National Report is made publicly available after the Review Meeting, unless the Contracting Party concerned notifies the Secretariat otherwise," Silye added.

"If nuclear power is to play its necessary part in the decarbonization of world energy supply, it is critical that barriers to the development of new facilities, such as uncertainty around liability arrangements, are removed."

— Steven McIntosh, Chairman, International Expert Group on Nuclear Liability (INLEX) and Senior Manager, Government and International Affairs, Australian Nuclear Science and Technology Organisation (ANSTO)

Building trust in nuclear's safety culture

By Michael Amdi Madsen

While nuclear and radiological accidents are few and far between, in-depth analyses show that weaknesses in safety culture are root causes in most cases. Since the Fukushima Daiichi nuclear accident in 2011, the safety culture concept that puts layers of safety first has been and is being implemented rapidly.

To better understand how attitudes are shifting towards strengthening safety in the nuclear industry, we spoke to Tom Mitchell, Chairman of the World Association of Nuclear Operators (WANO). At the helm of WANO for two years, and with over 40 years of experience in the nuclear industry, Mitchell is leading the nuclear operator community's focus towards a strengthened safety culture.

WANO is a non-profit organization that helps its global membership of commercial nuclear power plant operators achieve operational safety and reliability by providing peer reviews, and access to technical support and a global library of operating experience.

Q: After the Fukushima Daiichi nuclear accident, public support for nuclear power suffered over concerns of safety. How can trust with the public be restored?

A: That's a good question and something all of us in the nuclear industry think about. Trust is about confidence, and, since the Fukushima Daiichi nuclear accident, the nuclear industry has been looking to rebuild trust in three main areas: in technology, in oversight — which includes licensing and regulation — and in the operators who run nuclear facilities.

At WANO we don't have much interaction with the technology side of things, and regulation is a big part of what the IAEA does. But regarding operators, the fact that there is a WANO, a voluntary organization that gathers nuclear operators from around the world and seeks to maximize the focus on nuclear safety, should help instil confidence in operators and earn trust from the public.

"Since the Fukushima Daiichi nuclear accident, the nuclear industry has been looking to rebuild trust in three main areas: in technology, in oversight — which includes licensing and regulation — and in the operators who run nuclear facilities."

— Tom Mitchell, Chairman of the World Association of Nuclear Operators

Q: Strong safety standards are essential for nuclear facilities, but they can also increase operation costs. Is cost reduction a challenge to safety culture, and, if so, how can a balance be found?

A: Price is important to an essential product like electricity, and we don't find a contradiction between improving human performance and leadership aspects of safety and keeping prices competitive. In our experience, safety-focused organizations are efficient in running reactors with high-capacity loads. Safety changes can have a positive impact on reliability, which ultimately improves cost-effectiveness. We find improving safety culture to be complementary to reducing operation costs.

Q: How can leaders of nuclear operators encourage safety culture in their operations?

A: I've been a plant manager at two large nuclear power plants in Canada and the United States of America, and my view is that it's essential to lead by example. Leaders set an example in the way they interact with their staff and deal with issues when they arise.

It's important to have the right mindset as a leader, and WANO works with operators to develop effective leadership attributes. We have a broad definition of leadership and try to promote good qualities in training programmes across the board — dealing with issues present in different technologies, including safety.

Q: What example can the rest of the nuclear industry follow in terms of a strong safety culture, and why do you think they have it right?

A: A key attribute of WANO is that we learn from each other, both within our industry and outside of it. When you look outside nuclear, what comes to mind as a good example is the airline industry, and historically we have a relationship of studying one another, for instance how teams should function in a control room or cockpit.

One of the key things we do at WANO is identify strengths and learn what transpires in other industries, particularly positive lessons learned and better practices. Emulation and sharing of experiences are built into operators' mission statement — that's our job.

I also like to think that some of what we've done in the nuclear industry has migrated to other industries. If you go to a hospital for surgery in the United States, for example, you'll hear a lot of 'repeat-backs' and other tactics used by surgeons to avoid miscommunication and human error. These practices were piloted in nuclear.

Q: How can the IAEA further support safety culture in the nuclear industry?

A: The IAEA has a hugely important role to play in improving safety culture in the nuclear industry, and over the past decade the relationship between WANO and the IAEA has strengthened. As the chair of WANO, I want to see that continue.

A recent successful example of our cooperative work is that with new entrants in the nuclear industry. Working very closely with the IAEA and the Electric Power Research Institute, or EPRI, we put together a road map that guides countries through all the steps needed to transition to nuclear power, from construction to operation — placing safety and regulations first.

When you think about extending nuclear power operations and implementing new technology, the Agency has an important role in ensuring it's done safely, and it can work with the operator community to achieve that. This is critical, as extending operations and maintaining nuclear energy's viability is extremely important towards achieving global decarbonization and ensuring a safer planet for everyone.

"Emulation and sharing of experiences are built into operators' mission statement — that's our job."

— Tom Mitchell, Chairman, World Association of Nuclear Operators (WANO)

Workers dismantling the Turbine Hall at Ignalina Nuclear Power Plant.

(Photo: J. Donovan/IAEA)

Finding a new voice for nuclear

By Sama Bilbao y León

Sama Bilbao y León is Director General of World Nuclear Association, which represents the global nuclear industry and is responsible for promoting a wider understanding of nuclear energy among key international stakeholders. She has extensive experience in many domains, such as nuclear engineering, nuclear safety, and research and academia. Previously, she was Head of the Division of Nuclear Technology Development and Economics at the OECD Nuclear Energy Agency, and also Technical Head of the IAEA Water Cooled Reactors Technology Development Unit.

Despite its socioeconomic benefits and its role in mitigating climate change, nuclear power has a challenging reputation in a post-Fukushima world. Why is this and what can the industry do to change it?

Nuclear energy is the largest source of low-carbon electricity in advanced economies. Over the past 50 years, its use has avoided the emission of over 60 gigatonnes of CO_2, equivalent to almost two years' worth of global energy-related emissions[1]. In addition to its role in mitigating climate change, nuclear energy contributes to clean air by avoiding the emission of particulates and other pollutants. It does all this whilst working in a reliable, predictable and cost-effective manner. Furthermore, nuclear energy creates many local, long-term, high-quality jobs, as well as significant trickle-down socioeconomic benefits, important in the context of the post-COVID recovery[2]. Yet, despite all of this, public perception continues to be an issue for the industry, with concerns about safety and nuclear waste overshadowing all other accomplishments.

In contrast to what happened during the Chornobyl accident, the nuclear industry released huge amounts of data and information during the Fukushima Daiichi nuclear accident. And yet, in an era of 24/7 news coverage and information proliferation, which gives everyone the ability to promote their own views on the Internet, this higher level of transparency still failed to gain the trust of the general public.

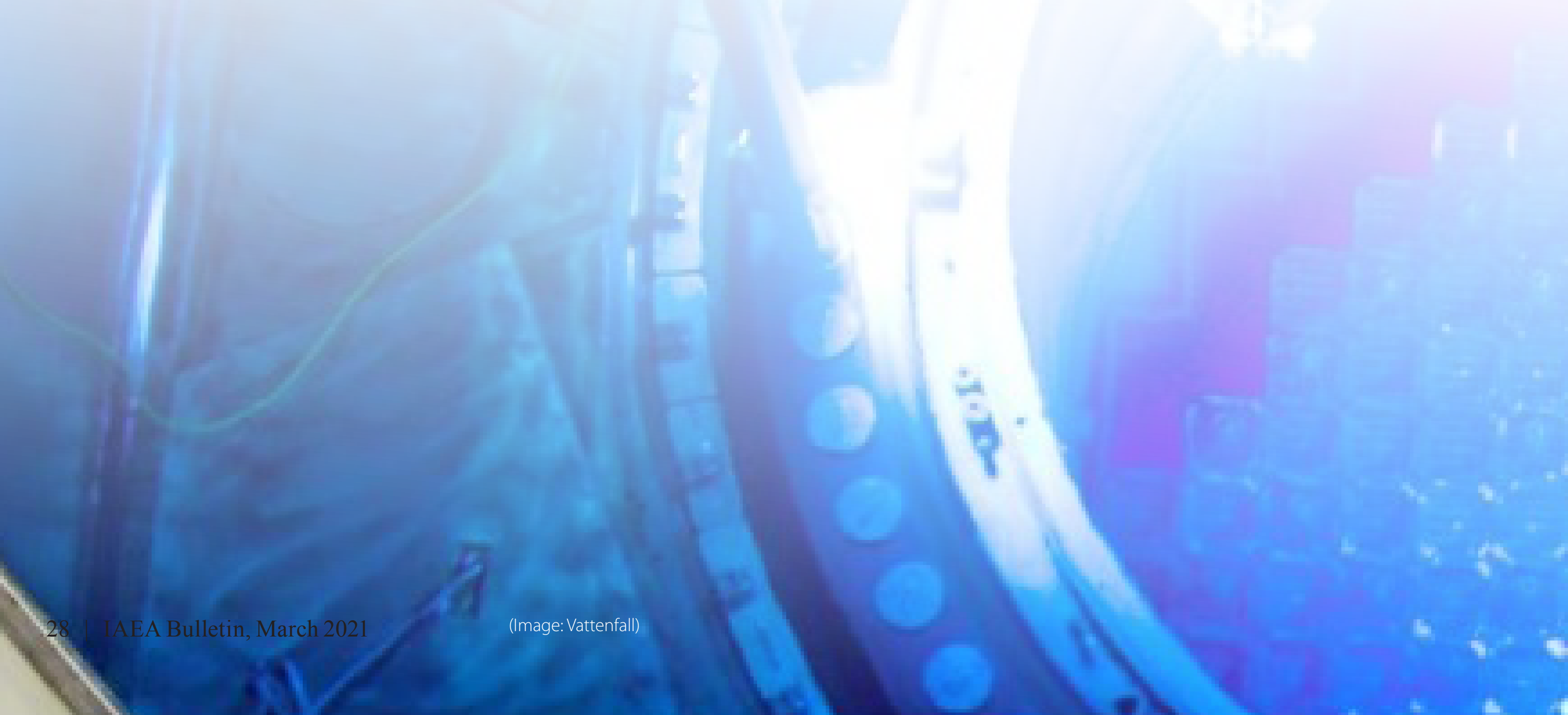
Trust is hard won and easily lost. It is earned as a result of a long, day-by-day effort; it cannot be established post-haste at a time of need, and it suffers following an adverse event. The nuclear industry has dutifully taken important steps to improve the way it is perceived, including demonstrating high standards, committing to transparency, and supporting local communities.

But nuclear energy is still viewed with suspicion, despite these efforts. It is still seen by many as too complex and unnatural. In this sense, "humanizing" the nuclear industry would go a long way towards gaining public trust. Presenting the many faces responsible for powering the nuclear industry — women and men of all ethnicities, ages, religions, and political orientations — would help the public better relate to nuclear energy because people trust people who are "just like them".

Clearly, facts by themselves are not enough for people to become comfortable with nuclear energy and radiation. It is time for

[1] *Nuclear Power in a Clean Energy System – Analysis - IEA*

[2] *Building a stronger tomorrow – Nuclear power in the post-pandemic world – World Nuclear Association (world-nuclear.org)*



(Image: Vattenfall)

the industry to better understand the emotions and motivations behind people's negative perceptions and to incorporate the human side of nuclear energy into the conversation. Due to the disconnect between reality and the perception of many individuals, the nuclear sector has proved to be a rich source of research for social and behavioural science scholars, who have produced a significant body of knowledge.

Unfortunately, this literature has not received significant attention from the industry and most translations from research into practice have largely been serendipitous. Most education, outreach and communications efforts on nuclear-related topics use traditional approaches and do not take enough advantage of learnings in psychology, sociology and behavioral science[3]. It is time for the nuclear community to utilize this knowledge to help us effectively make the case for nuclear energy in a post-Fukushima world.

We also need a consistent all-encompassing message as the range of technology options offered by the industry grows. A clear, unified voice from industry about the importance and applicability of the various technology options, both large and small, is key to ensure nuclear plays its full role in achieving decarbonization objectives and sustainable development goals. Extending the life of existing units will be indispensable for bridging the energy gap while we build the next generation of plants. Large reactors will remain the backbone of many clean energy systems, and considerable opportunities exist for the deployment of small modular reactors and advanced reactors, opening new markets and applications for nuclear energy. It is important that we, as a community, highlight the advantages of each nuclear technology option without undermining the alternatives. World Nuclear Association is hard at work establishing this constructive narrative[4] for the collective benefit of the full spectrum of technologies represented among our membership.

Nuclear energy, as well as the many applications of nuclear radiation, are simply too important to allow disinformation and fear to win the day. Beyond the significant contributions of nuclear power to decarbonization, clean air and economic development, the myriad of applications of radiation in, for example, medicine, agriculture, industry and space exploration may be in jeopardy if we fail to gain the trust of the public and decision makers. It is imperative that the nuclear community speaks with one voice and takes advantage of the learnings of modern social and behavioural sciences to effectively communicate the benefits of nuclear technology. It is our responsibility to ensure that future generations enjoy the option to choose nuclear energy if they so desire.

"Nuclear energy, as well as the many applications of nuclear radiation, are simply too important to allow disinformation and fear to win the day."

— Sama Bilbao y León, Director General, World Nuclear Association (WNA)

[3] Upcoming Special Issue of Nuclear Technology Journal on nuclear energy and social science

[4] The need for large and small nuclear, today and tomorrow – World Nuclear Association (world-nuclear.org)

Nuclear safety into the future

by Mike Weightman

Mike Weightman, a nuclear safety consultant, was the Chief Inspector of Nuclear Installations and Chief Executive Officer of the United Kingdom's Office for Nuclear Regulation before his retirement in 2013. He is a member of the International Nuclear Safety Group (INSAG), and was the leader of the IAEA International Expert Fact Finding Mission to Japan in May-June 2011.

It is now ten years since the Great East Japan Earthquake and the associated devastating tsunami that led to the nuclear accident at TEPCO's Fukushima Daiichi nuclear power plant. Various reports have been produced. Several conferences have been held. A range of detailed analyses and technical investigations conducted. Have we learned enough and implemented lessons sufficiently? What are the main messages from the accident for future generations?

Nuclear power can be a major component in addressing the global problems of clean energy and clean water. But public acceptance of the technology is low in many countries. Why should people believe in it if, some people say, when it goes wrong, it can cause major disruption to societies and harm to people? Society is changing, and fast. Technology is advancing peoples' lives. What does it all mean for the future of nuclear safety? Do we know?

Main lessons from the Fukushima Daiichi nuclear accident

Lessons from the accident have been listed in several analyses, most authoritatively in *The Fukushima Daiichi Accident* — the IAEA Director General's report of 2015. In essence, these lessons fall into two groups — technical and human/organizational — but they should be looked at as part of an overall system, and that in itself is a major lesson.

The technical lessons include:

- Having a consistent approach to setting design bases for external hazards based on a precautionary approach to uncertainty;
- Covering related hazards and multi-plant scenarios in safety analyses and provisions;
- Providing robust means to ensure fundamental safety functions (containment, control and cooling), including in severe accident scenarios;
- Providing robust means to monitor reactor and spent fuel safety parameters in severe accidents;
- Ensuring that off-site emergency monitoring and emergency control centres can work effectively under severe conditions; and
- Using an all-risk approach to off-site emergency decision-making.

Of course, it can be said that the requirements of existing IAEA safety standards cover such issues, but what matters is whether they are understood, followed and implemented. This requires paying attention to the human and organizational elements of safety, and that is where some of the major challenges lie. Some major lessons observed in this area are:

- Guarding against complacency and groupthink;
- Adopting a continuous improvement philosophy;
- Ensuring nuclear regulators are truly independent;
- Using a system approach to determining and improving the institutional

arrangements for ensuring nuclear safety; and
- Adhering to IAEA safety standards and other guidance, such as reports 4 and 27 of the International Nuclear Safety Group (INSAG).

The implementation of these lessons has been sparked through a variety of routes: regulators, international institutions, public concerns, countries that have nuclear power plants, and other stakeholders, as well as by, importantly, the nuclear industry itself. These have been chronicled in many places, notably in *Implementation and Effectiveness of Actions Taken at Nuclear Power Plants following the Fukushima Daiichi Accident* (IAEA TECDOC-1930); reports by the World Association of Nuclear Operators (WANO) and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA); and national, regulatory and utility publications. These lessons have illustrated the many areas where, on the basis of a culture of continuous improvement, changes have been made.

Into the future

Given what has been achieved to date, it is unlikely that any further significant lessons to improve nuclear safety will emerge from the ongoing decommissioning work at Fukushima Daiichi or related work elsewhere. Of course, as the inside of the stricken reactors is surveyed and material recovered and decommissioned, more research will assist in promoting confidence in analytical and severe accident modelling techniques or in enhancing them further.

Further consideration of a balance for optimized risk decisions involving low level radiation exposure will assist in determining emergency arrangements to minimize health and societal detriments.

With the increasing consideration of advanced reactor designs, the opportunity arises to look afresh at instilling a more fundamental approach to nuclear safety, utilizing passive safety philosophy, with less reliance on multiple complex protective systems. Additionally, ongoing research into accident tolerant fuels is potentially an important step forward that could also benefit present nuclear reactor safety.

However, the main areas where further advances in nuclear safety may be made in the ongoing programme of nuclear operation and development are those in the fields of human and organizational safety. In particular, we have to develop a more integrated and systemic approach for establishing and improving nuclear safety institutions to enable future generations to utilize safe and economical nuclear power to address the environmental challenges the world faces. And to do that, we must ensure, and demonstrate, that our hard-won lessons are not lost and, through a humble and responsive approach, earn the trust of a changing society. That is our duty.

To find out more on the implications for nuclear safety in a changing society, look for information about the forthcoming International Conference on a Decade of Progress After Fukushima-Daiichi: Building on the Lessons Learned to Further Strengthen Nuclear Safety.

"The main areas where further advances in nuclear safety may be made in the ongoing programme of nuclear operation and development are those in the fields of human and organizational safety."

— Mike Weightman, Nuclear safety consultant

IAEA fact-finding team leader Mike Weightman examines Reactor Unit 3 at the Fukushima Daiichi Nuclear Power Plant on 27 May 2011.
(Photo: G. Webb/IAEA)

The IAEA's contribution to improved nuclear safety over the past decades

By Gustavo Caruso

Gustavo Caruso is the Director of the Office of Safety and Security Coordination in the IAEA Department of Nuclear Safety and Security since 2016. He has more than 40 years of experience in nuclear safety-related fields. After the 2011 Fukushima Daiichi nuclear accident, he was designated as the Special Coordinator of the IAEA Action Plan on Nuclear Safety. He also coordinated work to create The Fukushima Daiichi Accident — Report by the Director General and five technical volumes. He began his career at the Nuclear Regulatory Authority (ARN) of Argentina.

Following the accident at the Fukushima Daiichi nuclear power plant on 11 March 2011, the IAEA set out to review and strengthen nuclear safety globally, drawing on lessons learned from the accident.

IAEA Action Plan for Nuclear Safety

Efforts began at the IAEA Ministerial Conference on Nuclear Safety convened in June 2011. There, the IAEA Action Plan on Nuclear Safety was developed. Endorsed by Member States in September 2011, the Action Plan defined a programme of work to strengthen the global nuclear safety framework in response to the accident.

Since the adoption of the Action Plan, significant progress has been made in several key areas, including assessments of the safety vulnerabilities of nuclear power plants; strengthening of the IAEA's safety peer review services; as necessary, revision of the relevant IAEA safety standards; improvements in emergency preparedness and response capabilities; capacity building in nuclear and radiation safety, as well as strengthening of safety culture; enhancements in communication and information sharing with and among national authorities; international cooperation; and strengthening of relevant international legal frameworks.

As part of their work under the Action Plan, operating countries introduced measures (that are still being implemented) to enhance nuclear safety, including those taken in response to the results from nuclear power plants' vulnerability assessments. In addition, the Action Plan reinforced the importance of having a questioning attitude when it comes to safety, by challenging existing assumptions about safety and their validity. By implementing the Action Plan, all parties involved demonstrated their commitment to enhance nuclear safety at nuclear power plants and other nuclear facilities worldwide.

The Action Plan also called on the IAEA Secretariat, Member States and relevant international organizations to review and strengthen the international emergency preparedness and response framework. Countries responded to the accident with immediate measures, which included carrying out 'stress tests' to reassess the design of nuclear power plants against site specific extreme natural hazards, installing additional backup sources of electrical power and water supplies, and strengthening the protection of plants against extreme external events.

Although most of the work under the Action Plan has concluded, there are still some longer-term activities that will be completed in the years to come. The focus on the lessons learned from the accident remain.

As part of the Action Plan, the IAEA held nine international experts' meetings that analysed key technical aspects of the Fukushima Daiichi accident. It also conducted over 15 international experts' missions to Japan and published reports on these missions reports to create a solid knowledge base for the future and continue strengthening nuclear safety worldwide.

The IAEA Fukushima Daiichi accident report

In 2015, the IAEA published The Fukushima Daiichi Accident, a comprehensive report on the accident. It provides an authoritative, factual and balanced assessment, addressing the causes and consequences of the accident, as well as lessons learned. The publication of the Report by the IAEA Director General and its five accompanying technical volumes was the result of an extensive international collaborative effort involving over 180 experts from 42 countries — with and without nuclear power programmes — and several international bodies. Their participation ensured a broad representation of experience and knowledge. An International Technical Advisory Group provided advice on technical and scientific issues.

The Report provides a description of the accident, as well as its causes, evolution and consequences, drawing upon data and information from up to March 2015, from a wide range of sources. It includes the results of the work carried out in implementing the IAEA Action Plan on Nuclear Safety, and it highlights the main observations and lessons. Significant amounts of data were provided by the Government of Japan and other organizations in Japan.

The Report calls for a systemic approach to safety that addresses the entire system by considering the dynamic interactions within and among three types of factors: human or individual (e.g. knowledge, thoughts, decisions, actions), technical (e.g. technology, tools, equipment) and organizational (e.g. management system, organizational structure, governance, resources). This systemic approach to safety works by addressing this complex system of interactions as a whole. The Report also highlights the importance of better examining the ways in which the strengths and weaknesses of all these factors influence one another in order to proactively reduce or eliminate risks.

Relevant international bodies worked together to develop clear and accessible explanations of the principles and criteria for radiation protection so that decision makers and the public could more easily understand their application. A better communication strategy is needed to convey the justification for such measures and actions to all stakeholders, including the public, the Report concluded.

It is also relevant to point out that, in spite of the magnitude of the accident in which three nuclear cores melted, no radiation-induced health effects were observed among workers or members of the public that could be attributed to the accident. This is in line with the conclusions that the independent United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported to the United Nations General Assembly in the years following the accident.

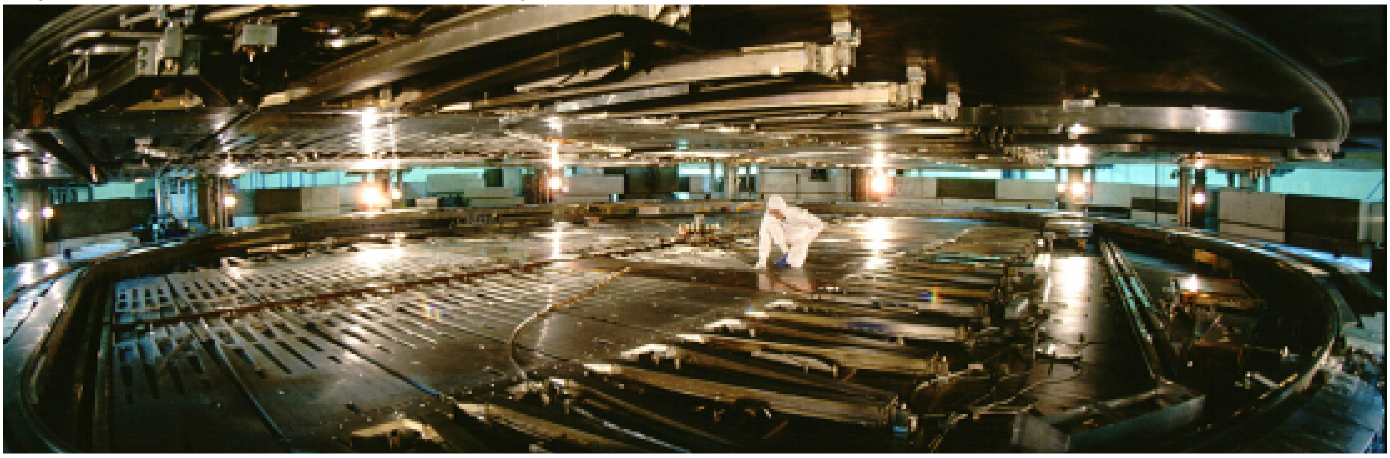
The Fukushima Daiichi accident underlined the vital importance of effective international cooperation on nuclear safety, and the IAEA is where most of that cooperation now takes place. As a result, the Report's recommendations have since been incorporated into national regulations, international safety standards and corresponding IAEA Safety Guides.

The Agency continues to analyse the relevant technical aspects of the Fukushima Daiichi accident and to share and disseminate lessons learned to the wider nuclear community. It will continue to support its Member States in implementing these lessons learned and will consider conducting any appropriate follow-up reviews of the implementation of these measures. The completion of the Report does not mean that our work is done — the IAEA's efforts in the formulation of its nuclear safety strategy must and will continue. It is essential that the IAEA maintain and build upon this momentum to strengthen global nuclear safety.

"The IAEA's efforts in the formulation of its nuclear safety strategy must and will continue. It is essential that the IAEA maintain and build upon this momentum to strengthen global nuclear safety."

— Gustavo Caruso, Director, Office of Safety and Security Coordination, IAEA Department of Nuclear Safety and Security

Cyclotrons: What they are and where to find them



Interior view of TRIUMF, in British Columbia, Canada, one of the 1300 cyclotron facilities around the world featured in a new IAEA database available online.
(Photo: Gordon Roy/TRIUMF)

Sounding more like a character from a science fiction film, a cyclotron is actually a particle accelerator — a machine that uses electromagnetic fields to propel charged particles at very high speeds and energies. Cyclotrons are used to produce radioisotopes for a type of medical drugs called radiopharmaceuticals, which diagnose and treat cancer. There are over 1500 cyclotron facilities around the world, and the IAEA has recently updated its interactive map and database featuring 1300 of these facilities across 95 countries.

Launched in 2019, the Database of Cyclotrons for Radionuclide Production is a tool to help experts such as radiopharmacists, and owners and users of medical cyclotron facilities to find and exchange technical, practical and administrative information on operating cyclotrons. It forms part of the IAEA's commitment to enhancing countries' capabilities to produce radioisotopes and apply radiation technology in health care.

"Cyclotrons are developing rapidly and will play an increasingly important role in the health care sector, especially in advanced medical imaging procedures, because cyclotron-produced radiopharmaceuticals are very efficient in detecting various cancers," said Amir Jalilian, Radioisotope and Radiopharmaceutical Chemist at the IAEA.

Medical imaging techniques such as positron emission tomography (PET) and single photon emission computed tomography (SPECT) rely on cyclotron-produced radioisotopes. However, unlike research reactors, which also produce radioisotopes, cyclotrons do not use nuclear material and are not subject to the same radiological safety and security considerations as reactors.

The IAEA database enables users to search for details about each facility, including the type, size and number of cyclotrons they house. Professionals in the field can connect and share expertise and information on their radiopharmaceutical products. The platform also promotes upcoming IAEA events and publications on the installation and application of cyclotrons.

The database forms part of the IAEA's efforts to support countries in producing radionuclides. The IAEA provides expert advice and technical guidance related to radiopharmaceutical production facilities; develops human resource capabilities through training courses and education programmes; and promotes research and development through coordinated research projects.

Owners and users of medical cyclotrons can contact the IAEA's Division of Physical and Chemical Sciences to send up-to-date information on their facilities by filling out an online form.

For more information, and to find out more about accelerators and their applications, visit the Database of Cyclotrons for Radionuclide Production and the Accelerator Knowledge Portal (AKP).

THE SCIENCE

A cyclotron is a type of particle accelerator that repeatedly propels a beam of charged particles (protons) in a spiral path. Medical radioisotopes are made from non-radioactive materials (stable isotopes) that are bombarded by these protons. When the proton beam interacts with the stable isotopes, a nuclear reaction occurs, turning the stable isotopes into radioactive ones (radioisotopes).

Some hospitals house their own cyclotrons and produce radioisotopes with short radioactive life on-site, which then become radiopharmaceuticals for direct use by patients. Thanks to recent advancements in the field, key radioisotopes such as technetium-99m (Tc-99m) and gallium-68 (Ga-68), are now also being produced in cyclotrons.

— Aleksandra Peeva

Climate change and coffee: Combating coffee rust through nuclear techniques

Coffee leaves display symptoms of coffee leaf rust disease at the CIFC in Portugal.
(Photo: I. Ingelbrecht/IAEA)

The coffee industry generates approximately US $ 100 billion per year. But with climate change and the changing weather patterns it produces, the conditions that were once suitable for coffee plants are deteriorating in many traditional growing areas, and the incidence of coffee leaf rust — a disease that kills coffee trees — is on the rise.

The IAEA, in partnership with the Food and Agriculture Organization of the United Nations (FAO), has been working with national experts to alleviate the stress of coffee leaf rust on coffee trees using nuclear techniques. A first for the IAEA, experts are being trained to use plant breeding techniques to develop coffee varieties that are resistant to the fungus that causes coffee leaf rust. This training is part of a five-year coordinated research project where scientists from six countries have been conducting research on disease resistant coffee plant varieties.

"Growers have been noticing the effects of climate change on their coffee crops resulting in lower harvests and the fact that erratic rainfall, which a lot of these coffee-producing areas are experiencing, favours the spread of disease," said Ivan Ingelbrecht, Head of the Plant Breeding and Genetics Laboratory at the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture. "The arabica variety of coffee is usually grown in cooler climates, on the slopes of mountains, in shaded areas, but now we are seeing temperatures increase as you go up the mountain, which has an impact on the spread of diseases like coffee leaf rust."

Farming coffee in Costa Rica

In Costa Rica, most coffee plantations rest on small to medium plots of land. These family-owned farms oftentimes rely on seasonal workers to pick the coffee beans by hand. This process is timely and intensive, requiring up to 14 000 workers from Costa Rica and Panama during the harvesting season.

But as climate change exacerbates weather patterns that are unsuitable for coffee plants, seasonal work opportunities diminish, impacting livelihoods. Changing rainfall patterns and rising temperatures have also been found to shorten the time it takes for a coffee plant with leaf rust to become infectious — increasing the infection rate and spread from one plant to another.

Working with the IAEA and FAO, the Coffee Institute of Costa Rica (ICAFE) has been researching the impact of coffee leaf rust throughout the country and how to manage it. With records showing a rise in temperature and changes in rainfall patterns since 2010, coffee growers are finding that they cannot harvest their crops at the usual times.

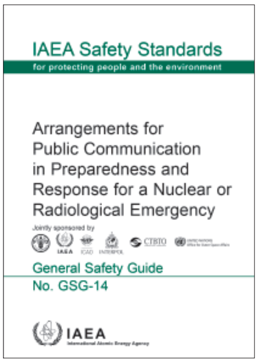
"The reduction in productivity affects the income of growers, reducing the resources available to assist the plantation and putting the conservation of the farms for future generations at risk. This may affect the future model of land possession in our country," said Reina Céspedes, a biotechnologist at ICAFE. "Advancing the genetics of coffee trees is essential to improving the quality of life for coffee-producing families, maintaining land possession and contributing to environmental sustainability."

Coffee research in Portugal

Portugal, also involved with the FAO–IAEA project, is home to the Coffee Leaf Rust Research Centre (CIFC). About 3600 samples of coffee rust from 40 countries around the world have been evaluated at the CIFC, where scientists have identified 50 different types of coffee leaf rust across 23 varieties of coffee tree. During the project, three new variants of the coffee rust pathogen were identified. Research into these forms of global coffee rust will facilitate the identification of a variety of coffee plant that is resistant to coffee rust — a tall order considering the diverse range of coffee rust species.

"We were first made aware in 2011 of the impact changing weather patterns were having on coffee harvests by coffee breeders, pathologists and technical bulletins from coffee growing countries," said Vítor Várzea, a plant pathologist at the CIFC. "It is urgent to find and characterize new varieties of coffee plants that are resistant to coffee leaf rust and can then be extended to other countries."

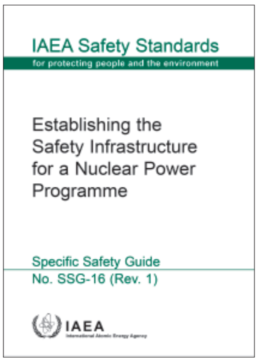
— Carley Willis



Arrangements for Public Communication in Preparedness and Response for a Nuclear or Radiological Emergency

supports Member States in developing arrangements for communicating with the public and the media and coordinating official information in the response to a nuclear or radiological emergency. These arrangements facilitate the successful implementation of protective actions and the delivery of consistent messages. Specifically, it describes the infrastructure and processes needed to provide useful, timely, truthful, consistent, clear and appropriate information to the public in the event of a nuclear or radiological emergency; to respond to incorrect information and rumours; and to respond to requests for information from the public and from the news and information media. It will help ensure effective and uniform public information and media communications arrangements during nuclear and radiological emergencies. The guidance is applicable for such emergencies, irrespective of the initiator, whether that be a natural event, human error, mechanical or other failure, or a nuclear security event.

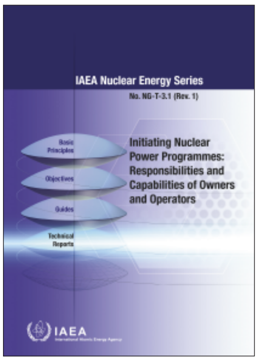
IAEA Safety Standards Series No. GSG-14; ISBN: 978-92-0-109019-5; English Edition; 48.00 euro; 2020



Establishing the Safety Infrastructure for a Nuclear Power Programme

provides guidance on the establishment of a national nuclear safety infrastructure as a key component of the overall preparations required for emerging nuclear power programmes. It provides recommendations, presented in the form of 200 sequential actions, on meeting the applicable IAEA safety requirements during the first three phases of the development of a nuclear power programme. It is intended for use by persons or organizations participating in the preparation and implementation of a nuclear power programme, including government officials and legislative bodies, regulatory bodies, operating organizations and external support entities.

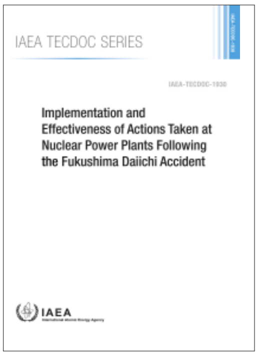
IAEA Safety Standards Series No. SSG-16; ISBN: 978-92-0-115310-4; English Edition; 40.00 euro; 2015



Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators

provides information on the establishment and development of the owner/operator so that it can discharge its responsibilities throughout the phases of a nuclear power programme. It also discusses the management of the interfaces between the owner/operator and other stakeholders.The development of a nuclear power programme infrastructure includes the establishment of policies and strategies in areas such as human resource development, nuclear fuel cycle and waste management, industrial involvement and nuclear safety. It also requires the establishment of a legal and regulatory framework that creates an environment enabling the project to be implemented in a transparent and effective manner.

IAEA Nuclear Energy Series No. NG-T-3.1 (Rev. 1); ISBN: 978-92-0-104619-2; English Edition; 30.00 euro; 2020



Implementation and Effectiveness of Actions Taken at Nuclear Power Plants following the Fukushima Daiichi Accident

addresses the challenges faced and the ongoing needs of Member State organizations that have been implementing and maintaining post-Fukushima actions. It discusses the actions taken (or to be taken) and good practices, and describes effective solutions to issues in implementation, verification, qualification and maintenance. Also discussed are the approaches to measuring and maintaining effectiveness of actions as well as an analysis of merits, costs and benefits. Examples in decision making for implementation and follow-up policies, programmes and procedures to ensure sustainability in the long term are presented.

IAEA-TECDOC-1930; ISBN: 978-92-0-120720-3; English Edition; 18.00 euro; 2020

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