1. **FOOD and AGRICULTURE**

In the 21st century, the challenges in the field of food and agriculture were wide, ranging from enhancing crop production to managing water and soil effectively, controlling livestock diseases, tackling insect pests and ensuring food safety. With a focus on practical solutions, the efforts within the TC programme were aimed at enhancing global food security and sustainability.

At the dawn of the century, agricultural needs became evident, necessitating innovative solutions. The TC programme strategically addressed these challenges by enhancing crop mutation breeding, improving soil and water management practices, implementing advanced disease detection methods in livestock, innovating insect pest control strategies and ensuring food safety through analytical techniques and irradiation.

By providing training, equipment and policy support, the TC programme aimed to empower Member States in adopting sustainable agricultural practices, enhancing productivity and mitigating risks to food safety. These initiatives underscore the importance of collaborative efforts to meet the evolving demands of food and agriculture in the mid-term perspective.

1. **Crop production.**

***Challenges:*** *Need for sustainable intensification of both crop and forage/grasses production systems, integration of new varieties adapted to diverse climate conditions. Limited access to advanced technologies for crop mutation breeding and biotechnologies in regions, where the imperative to enhance food security was particularly pressing.*

At the outset of the century, the pressing need for improved crop production capabilities became evident. The problem of limited access to advanced technologies for crop mutation breeding, crucial for addressing food security concerns, particularly in developing regions, posed a significant global agricultural challenge. In response, the IAEA within the framework of the TC programme, has strategically focused on enhancing crop production through radiation-induced mutation breeding and efficiency-enhancing biotechnologies. Recognizing the interconnected nature of agriculture, the IAEA’s efforts have extended beyond crop-centric approaches. Sustainable crop productivity initiatives also have encompassed training programs and equipment distribution to enhance crop resilience.

**IAEA’s multifaceted approach**

Within the framework of the TC programme the IAEA has comprehensively addressed the challenge of limited global access to advanced crop production technologies, with a specific emphasis on the following issues.

**Food-crop mutation breeding techniques.** The IAEA provided training and equipment for improved mutation breeding techniques to Member States, enhancing traits like drought resistance and productivity. Institutional capacities were built for radiation-induced mutation breeding and accelerated breeding, leading to operational labs applying enhanced biotechnology and mutation techniques.

**Crop characteristics improvement.** The focus of the IAEA was on increasing the availability of crops with improved characteristics, such as resilience to climatic conditions, pests, and droughts. New mutant lines of local crops with enhanced agronomic traits and quality characteristics were developed, contributing to sustainable intensification of crop production systems in various Member States.

**Sustainable crop productivity.** Training programs and equipment distribution aimed to improve sustainable crop and livestock productivity, fostering the development of new crop varieties resilient to various climatic conditions. Breeding programs were optimized using mutation induction and biotechnologies, promoting integrated and climate-resilient production systems.

**Forage and grasses production.** Similar efforts were extended through the TC programme to forage and grasses, with a focus on improving grass/forage seeds mutation breeding techniques. Institutional capacities in interested Member States were enhanced for radiation-induced mutation breeding, leading to the development of new grass varieties with increased properties. This approach aimed to increase sustainable intensification of forage and grasses production systems.

**Achievements and results**

Notable progress in global crop production has been achieved in those Member States who participated in the TC Programme activities related to crop production. The IAEA has facilitated knowledge exchange, delivered vital technical training and distributed cutting-edge equipment to Member States. These initiatives aimed to increase sustainable intensification in crop production systems by integrating new crop varieties with improved characteristics and adapted to local climate conditions. Similarly, efforts have been directed towards enhancing the sustainable intensification of forage and grasses production systems, aligning with the overarching goal of fostering resilience to climate variability and improving overall agricultural productivity.

**Diversification of crop varieties.** Implementation of enhanced biotechnologies and mutation breeding techniques with support from the IAEA led to the development of new crop varieties with improved characteristics in many Member States, increasing resilience to climatic conditions, pests and droughts.

**Operational labs.** The establishment and optimization of operational labs using enhanced biotechnology and accelerated mutation contributed to increased production with improved traits.

**Sustainable intensification.** The IAEA's efforts resulted in a notable increase in sustainable intensification of crop and forage production systems. Laboratories capable of irradiating foraged seeds to improve nutrient properties became operational, furthering the integration of new crop varieties adapted to climate disparities.

**Impact and perspectives.** By providing support in the integration of new crop varieties tailored to diverse climate conditions, the IAEA addressed the pressing need for resilient and durable farming methods. The IAEA's efforts were instrumental in bolstering food security initiatives and promoting sustainable agricultural intensification, especially in regions with limited access to advanced technologies for crop mutation breeding and biotechnologies. The perspectives indicate a positive trajectory for enhanced food security and adaptive agricultural practices in these regions.

1. **Agricultural water and soil management.**

***Challenges:*** *Necessity for the sustainable enhancement of water and soil management, incorporating new methodologies and policies to foster resilience and address limited access to advanced technologies in regions with pressing agricultural challenges.*

The IAEA's TC programme in the early 2000s was shaped by a substantial demand for innovative progress in managing agricultural water and soil. The limited availability of advanced technologies for soil and water conservation, especially in regions facing severe agricultural issues, required transformative steps. The IAEA has acknowledged the needs going beyond traditional methods to encompass policy suggestions, the development of research capacity and the promotion of sustainable practices.

**IAEA’s multifaceted approach**

**Policy and guideline support.** The IAEA has developed a number of practical policies and guidelines for improved land and water management practices, aiming to enhance crop yield, soil quality, and conserve natural resources in member States. These initiatives have played a crucial role in providing a structured framework for sustainable agricultural practices worldwide.

**Research and capacity building.** Training initiatives on isotopic techniques for improved land and water management have been delivered through a number of TC projects, cultivating the expertise of agricultural professionals. Such efforts were aimed at the establishment of research capacities in national agricultural research systems (NARS) and laboratories deploying nuclear, isotopic and related techniques worldwide.

**Soil erosion and sediment control.** Training programs addressing soil erosion and sediment origin assessment have been conducted, establishing capacities for informed decision-making in Member States. The IAEA has developed recommendations, guidelines and policies pertaining to soil erosion and sediment origin that have been successfully utilised in interested countries.

**Greenhouse gas (GHG) emission reduction.** A significant focus has been directed towards training on GHG emissions from agricultural practices. The establishment of capacities to comprehend GHG emissions has led to the initiation of new programs, initiatives or recommendations with the ultimate aim of reducing GHG emissions.

**Hydrology and groundwater processes.** Numerous training sessions on hydrology and groundwater processes have been implemented, contributing to improved understanding and capabilities in this field.

**Climate change adaptation.** The IAEA has extended training on evaluating the effectiveness of climate change adaptation strategies and climate-smart agriculture. The establishment of capacities for evaluation has influenced decisions in climate change adaptation and climate-smart agriculture in Member States.

**Achievements and results**

In response to the needs in the field of agricultural water and soil management the IAEA has launched a number of initiatives aimed to redefine practices, policies and capacities, fostering a global shift towards sustainable agricultural practices in regions facing severe agricultural challenges. These efforts have encompassed the promotion and adoption of improved water and soil management practices, aligning with the broader objective of advancing climate-smart agriculture and bolstering resilience while reducing greenhouse gas emissions. Other efforts have been directed towards enhancing land and soil fertility as well as resistance to climate change and other environmental stresses. These efforts aimed to enhance control over land degradation and soil erosion within agricultural landscapes, fostering improved productivity and environmental sustainability on a global scale.

**Policy integration.** The IAEA's efforts in providing guideline recommendations have manifested in the ratification of policies and regulations dedicated to improved agricultural water and soil management practices in Member States. These policies include provisions for breeding programs aimed at developing crop and grass varieties resilient to climate variability and other environmental stresses.

**Capacity empowerment.** Training initiatives conducted within the TC programme have enhanced the skills of agricultural professionals, leading to the development of guidelines and practices promoting soil-water nutrient management. These guidelines have been disseminated on a regional level, reflecting the successful implementation of enhanced practices in the field. Furthermore, capacity-building efforts have been directed towards breeding programs for crops and grasses, ensuring that professionals are equipped with the knowledge and skills necessary to develop and implement new varieties adapted to local climate conditions.

**Operational enhancement.** The establishment and optimization of capacities in laboratories using nuclear, isotopic and related techniques have contributed to increased awareness and adoption of new methodologies for sustainable water and soil management practices worldwide. These laboratories play a crucial role in assessing soil erosion, sediment origin, hydrology, groundwater processes and GHG emissions from agricultural practices, thereby facilitating informed decision-making and effective implementation of climate-smart agriculture strategies.

**Impact and perspectives.** The IAEA has aimed at reshaping agricultural water and soil management practices to make them more effective and efficient. Such efforts have resulted in the adoption of enhanced methods and policies, marking a step forward in addressing the complex challenges faced by agriculture at the dawn of the 21st century. The perspectives in this field include further efforts to improve control over land degradation, increased soil fertility, heightened resistance to climate change and environmental stresses, and the integration of new crop varieties adapted to diverse climate conditions. By providing support in these areas, the IAEA continues to play a crucial role in advancing sustainable agricultural practices and enhancing food security worldwide.

1. **Livestock production.**

***Challenges:*** *Limited access to advanced technologies for livestock disease detection, characterization, and control.*

At the beginning of the 21st century, the main concerns of Member States referred to livestock production capabilities. Limited access to advanced technologies for detecting and controlling diseases in livestock, which is vital for ensuring food security was identified as one of the biggest problems in the field of agriculture. Responding to this, the IAEA directed its efforts toward increasing livestock production by implementing advanced diagnostic and disease control technologies, including mutation breeding for improved feed and forage.

**IAEA’s multifaceted approach**

The IAEA has proposed comprehensive strategy to address challenges in livestock production ranging from advanced disease detection, characterization and control to the development and implementation of national surveillance plans. The overall focus of the relevant projects within the TC programme extended to mutation breeding programs and comprehensive training on breeding management systems to strengthen livestock breeds and improve overall productivity.

**Disease detection, characterization, and control.** The IAEA has delivered training and equipment for the detection, characterization and control of animal and zoonotic diseases to interested Member States. Veterinary laboratories have been equipped and staff trained in nuclear and nuclear-related diagnostic technology. Capacities for disease detection and control have been established, meeting international accreditation standards. Additionally, plans for improved surveillance and control have been implemented across Member States.

**Livestock disease surveillance.** Member States’ national plans for the detection and control of animal and zoonotic diseases have been developed and implemented. The focus was on increasing livestock productivity by better detection and control of diseases, including transboundary animal diseases and those of zoonotic importance.

**Mutation breeding for feed and forage.** The IAEA has provided training on mutation breeding programs for grasses, particularly for improving local livestock feed and forage production. Laboratories capable of irradiating foraged seeds to improve nutrient properties have been widely established, leading to the development of new grass varieties and improved feed and forage resources.

**Enhanced breeding management.** Training programs on enhanced breeding management systems and breed strengthening have been delivered through various TC projects, leading to the establishment and enhancement of reproduction centres and service stations. These efforts haves aimed at strengthening breeds, implementing improved management systems and ultimately increasing livestock productivity for the benefit of interested Member States.

**Achievements and results**

Through participation in the TC programme, Member States have boosted their livestock production. With the support from the IAEA, advanced diagnostic technologies and effective disease control measures have led to a notable decrease in livestock diseases. The implementation of national disease surveillance plans, bolstered by IAEA assistance, have effectively managed transboundary diseases, thereby enhancing productivity levels. The establishment of mutation breeding laboratories has facilitated the creation of new grass varieties, enriching feed and forage resources and fostering an increase in overall livestock productivity.

**Enhanced disease management.** Implementation of advanced diagnostic technologies and disease control measures supported by the IAEA has led to improved disease management across Member States. Veterinary laboratories with trained staff and established capacities have reported a significant reduction in the prevalence of livestock diseases. Capacities for the detection, characterization and control of animal and zoonotic diseases have been established, ensuring better surveillance and control strategies.

**Effective disease surveillance.** National plans for the detection and control of animal and zoonotic diseases, as supported by the IAEA, have been widely implemented. This has led to better control of transboundary animal diseases and those of zoonotic importance. Plans and strategies for improved surveillance and control of animal and zoonotic diseases have been implemented, resulting in enhanced disease control measures and improved livestock health.

**Enriched feed and forage resources.** The establishment of laboratories capable of irradiating foraged seeds has facilitated the development of new grass varieties and improved feed and forage resources worldwide. Such efforts have enhanced agricultural outcomes and contributed to an increase in livestock productivity. Improved capacities to develop new feed and forage resources have been established, ensuring a sustainable and nutritious diet for livestock.

**Optimized breeding management.** IAEA training programs on enhanced breeding management systems and breed strengthening have resulted in better breeds and improved management systems across Member States in the 21st century. Operational reproduction and service centres using enhanced genetic breeding have become more widespread. Strengthened breeds have been developed and improved management systems implemented, leading to increased livestock productivity and resilience.

**Impact and perspectives.** By addressing identified challenges through the TC programme, the IAEA has contributed to the enhancement of food security in regions facing pressing agricultural challenges. The positive trajectory indicates improved livestock productivity, disease control and sustainable agricultural practices in these regions. The IAEA's efforts have paved the way for adaptive and resilient livestock production systems, ensuring a more secure and productive global food supply. The increase in livestock productivity by better detection and control of diseases, improved forage resources and optimized breeding management demonstrates the tangible impact of the TC programme in promoting sustainable crop and livestock productivity and climate resilience.

1. **Insect pest control.**

***Challenges:*** *Limited methods for controlling insect pests in agriculture and human/animal health, need for innovative strategies in insect pest control.*

In the early 21st century, a major problem in insect pest control was the lack of effective methods to reduce their impact on agriculture, human health, and animal well-being. Traditional reliance on chemical pesticides was proving unsustainable due to the emergence of resistance, environmental concerns, and unintended consequences. This necessitated the urgent development and implementation of innovative strategies in insect pest control. The demand for alternative and sustainable approaches became increasingly evident. The main task before the TC programme was to bridge the gap between the escalating threat posed by insect pests and the need for novel, integrated solutions to safeguard global food security and public well-being. This moment underscored the imperative for a paradigm shift towards more diverse and environmentally friendly approaches in the pursuit of effective insect pest management.

**IAEA’s multifaceted approach**

Recognizing the limitations of traditional methods, the IAEA has initiated mass insect breeding programs in agriculture, supported area-wide pest control strategies and assessed the effectiveness of the Sterile Insect Technique (SIT). These efforts extend to human and animal health, where the IAEA has facilitated mass insect breeding and formulated area-wide control strategies in interested Member States. This comprehensive approach has aimed to innovate pest control strategies, enhance regional cooperation and contribute to global food security and public well-being.

**Mass insect breeding in agriculture.** The IAEA has initiated training and provided equipment for mass insect breeding in agriculture. Staff participation in training programs aimed at developing techniques for integrated pest management saw a significant increase. Capacities for insect control, breeding, and release programs were established, improving skills for mass insect breeding in agriculture.

**Area-wide strategies for pest control.** Through the TC programme the development of strategies for area-wide control of insects in agriculture has been actively supported. This included planning and implementing regional strategies for pest control, resulting in enhanced capacities and the implementation of effective strategies in major crops and livestock.

**Assessment of SIT effectiveness.** The TC programme has played a crucial role in supporting the assessment of the effectiveness of the SIT for insect eradication and control in agriculture. National and regional centres have received support on assessment systems, resulting in reports and recommendations on the effectiveness of SIT techniques in interested Member States.

**Mass insect breeding in human/animal health.** Parallel efforts have been made in human and animal health, where the IAEA has provided training and equipment for mass insect breeding. Capacities have been established for insect control programs promoting and protecting human health, contributing to increased livestock productivity through better disease detection and control.

**Area-wide control strategies in human/animal health.** Similar to agriculture, the TC programme has supported the formulation of strategies for area-wide control of insects in human/animal health. These efforts included planning, development and implementation of regional strategies, resulting in drafted strategies and their effective application in pest control programs.

**Assessment of SIT effectiveness in human/animal health.** The IAEA has extended support for the assessment of SIT effectiveness in human/animal health, providing decision support systems and guidelines to national and regional centres.

**Achievements and results**

The implementation of innovative projects through the TC programme has led to notable advancements in insect pest control. Agricultural productivity soared as farmers gained better control over crop diseases, ensuring healthier yields. Livestock thrived too, benefiting from improved disease detection and management practices. These advancements boosted productivity and enhanced the sustainability of crop and livestock systems, making them more resilient to the challenges posed by a changing climate. Achieved results underscore the importance of ongoing collaboration with the IAEA to address global challenges in pest management effectively.

**Development of mass insect breeding.** The initiation of mass insect breeding programs in agriculture and human/animal health, facilitated by training and equipment provisions, has resulted in heightened skills and capacities among involved authorities in Member States. Capacities on mass breeding of insects in both agriculture and human/animal health have been established, empowering communities to take proactive measures in pest management and reducing reliance on chemical pesticides. Implementation of strategies for area-wide control of insects has been successfully carried out, leading to reduced pest-related damages and improved agricultural productivity.

**Effective deployment of area-wide strategies.** The adoption and implementation of area-wide strategies for pest control have resulted in a notable decrease in pest-related damages to major crops and livestock across Member States. Capacities for the formulation of strategies for area-wide control of insects in both agriculture and human/animal health have been established, allowing for the effective deployment of integrated pest management techniques. Recommendations on the effectiveness of techniques for insect eradication and control have been implemented.

**Strategic insights from SIT assessment.** The assessment of the effectiveness of the SIT has emerged as an effective practical outcome, providing valuable insights into strategic improvements in insect eradication. Skills used in programs of mass insect breeding for agricultural and human/animal health purposes have been leveraged to enhance pest control efforts. Reports and recommendations by the IAEA have guided the refinement of pest control strategies, facilitating the implementation of effective pest eradication and control measures.

**Impact and perspectives.** The TC programme has brought tangible positive changes in the field of insect pest control. Reduced pest prevalence and damages to crops and livestock signify a shift towards more sustainable agricultural and health practices. Improved disease control measures and heightened livestock productivity demonstrate the tangible benefits of integrated pest management strategies. Continued collaboration and investment in innovative approaches will be essential to sustain these positive trends and ensure long-term resilience in insect pest control efforts worldwide.

1. **Food safety.**

***Challenges:*** *Limited analytical techniques for quality control, insufficient food tracing technologies, inadequate infrastructure for food irradiation.*

Food safety has been always considered as a critical concern. At the dawn of the 21st century, traditional methods proved insufficient to address the complexities of modern food production and distribution. The reliance on conventional approaches faced challenges due to evolving pathogens, globalization of food trade, and emerging contaminants. This highlighted the urgent need for innovative strategies to ensure the safety and integrity of the global food supply chain. The TC programme recognized the pressing demand for integrated solutions to safeguard public health and promote sustainable food practices amidst evolving risks and uncertainties. This moment highlighted the need for a broad approach to food safety, emphasizing teamwork, research, and technology sharing to address new risks and improve global food security.

**IAEA’s multifaceted approach**

**Equipment and training for food quality control analysis.** The IAEA provided equipment and training for analysing food quality, including monitoring contaminants and residues. These efforts aimed to strengthen the capacity of Member States in detecting and mitigating food safety hazards effectively.

**Food tracing techniques.** The TC programme supported initiatives to improve food tracing capabilities, enabling the monitoring of food authenticity and traceability. Recommendations by the IAEA for further action were provided to promote the adoption of internationally accredited analytical procedures and regulations to control contaminants and residues in foods.

**Food irradiation techniques.** The IAEA also provided equipment and training in techniques for food irradiation, enhancing post-harvest quality control measures to interested Member States. Capacities in food irradiation were utilized to improve sanitary and phytosanitary conditions in food production, resulting in reduced post-harvest losses and increased trade of irradiated products.

**Achievements and results**

The projects supported by the TC programme have contributed to significant progress in the field of food safety. In the 21st century the TC programme aimed at enhancing food authenticity, quality, and reducing contaminants have bolstered consumer confidence and elevated food safety standards to ensure the integrity of food supply chains. The collaborative efforts facilitated by the IAEA so far underscore Member States needs in continual improvement in food safety practices, ensuring safer and more reliable food systems.

**Enhanced food safety monitoring.** The provision of equipment and training for food quality control analysis has resulted in heightened capabilities for monitoring contaminants and residues in food products. Capacities are used in the analysis for food quality control and monitoring of contaminants and residues, leading to improved food safety standards and reduced health risks associated with consuming contaminated foods in Member States participating in relevant TC projects.

**Improved food traceability.** With IAEA support provided through the TC programme, Member States have been able to establish robust systems for monitoring food authenticity and traceability. Capacities are used to monitor the authenticity and trace the origin of food products, facilitating better regulatory oversight and increasing consumer confidence in the safety and integrity of food supply chains.

**Strengthened post-harvest quality control.** The implementation of food irradiation techniques, coupled with equipment and training support by the IAEA, have strengthened post-harvest quality control measures across Member States. Capacities in food irradiation are applied to food post-harvest quality control, leading to a reduction in post-harvest losses and increased trade opportunities for irradiated products, thereby enhancing food security and economic growth.

**Impact and perspectives.** The approach employed by the IAEA in food safety has led to positive changes, reducing the prevalence of contaminants and residues in the food supply chain. Actions taken to improve food quality and reduce contaminants and residues in the food supply, as well as to improve food authenticity, are in line with national food programs or strategies. Improved food authenticity and quality controls have enhanced consumer confidence and public health outcomes. Continued collaboration and investment in innovative approaches will be essential to sustain these positive trends and ensure long-term resilience in food safety efforts worldwide.

1. **HUMAN HEALTH and NUTRITION**

The 21st century is characterized by rapidly evolving healthcare landscape. In this context, addressing diverse challenges in cancer diagnosis and treatment, human health and nutrition, and radiological applications has been paramount for promoting global well-being. Member States across the globe have encountered multifaceted obstacles, ranging from limited access to advanced diagnostic technologies and inadequate infrastructure for cancer treatment to insufficient analytical capacity in isotope techniques for nutrition assessment. Meanwhile, the lack of resources to produce and ensure the quality of radioisotopes and radiopharmaceuticals has made it hard to provide the best healthcare solutions especially for LDCs.

Recognizing the urgency of these challenges, the IAEA has taken proactive steps to address deficiencies in healthcare, particularly in underserved regions and vulnerable populations. Through the TC Programme, the IAEA has strategically focused on leveraging innovative approaches and isotope techniques to tackle the complexities of cancer diagnosis and treatment, nutrition-related issues, and radiological applications.

The multifaceted approach embraced by the IAEA has encompassed a wide spectrum of TC project, ranging from targeted training in isotope techniques for nutrition assessment to the procurement and delivery of advanced medical equipment for cancer diagnosis and treatment. Through collaborative efforts and knowledge transfer, the TC programme has facilitated the exchange of best practices, enabling Member States to adapt successful strategies to their unique contexts. The TC programme has addressed the root causes of healthcare disparities and advancing radiological applications, thus fostering resilience and empowering healthcare capacity of Member States.

1. **Cancer diagnosis and treatment.**

***Challenges:*** *Limited access to advanced diagnostic technologies, inadequate infrastructure for cancer treatment, shortage of trained healthcare professionals, limited availability of cancer control plans, low quality assurance in cancer care, generally unaffordable cancer care.*

At the beginning of the 21st century, the IAEA recognized the urgent need for enhanced cancer diagnosis and treatment capabilities in developing nations. The limited access to advanced diagnostic and treatment facilities for cancer patients, particularly in these regions, posed a significant global health challenge. In response, the IAEA, through the TC Programme, strategically focused on addressing this issue by leveraging nuclear technology.

**IAEA’s multifaceted approach**

The IAEA has recognized the urgency to address the challenges of cancer care in developing nations and has leveraged its expertise and partnerships to deliver impactful interventions aimed at improving cancer control planning, increasing access to essential radiotherapy services, and advancing nuclear medicine capabilities. Through initiatives such as imPACT Reviews and the procurement of advanced medical equipment, the IAEA has catalyzed transformative changes in cancer care delivery.

**Comprehensive cancer control assessments (imPACT Reviews)**. In collaboration with the World Health Organization (WHO), the International Agency for Research on Cancer (IARC) and other relevant partners, the IAEA has conducted imPACT Reviews to assess existing cancer care capacities in interested Member States. These reviews aimed to formulate evidence-based strategies for effective cancer control, enhancing the readiness of health systems to provide comprehensive cancer care.

**Development of strategic document on cancer control.** As a follow-up to the imPACT reviews, strategic documents on cancer control have been developed with comprehensive support from the IAEA. These documents have provided guidance and frameworks for Member States to implement comprehensive cancer control strategies tailored to their specific needs.

**Resource mobilization support.** The IAEA has provided resource mobilization support to Member States for unfunded cancer-related activities, facilitating the development of funding proposals and bankable documents to support cancer control initiatives.

**Equipment procurement and delivery.** Within the framework of the TC programme, the IAEA has facilitated the procurement and delivery of advanced radiotherapy equipment, such as linear accelerators (LINACs), and has provided support to strengthen quality assurance protocols in cancer care facilities across interested Member States. Additionally, support has been provided for the development of QA/QC protocols in nuclear medicine.

**Training, capacity building and guidelines development.** The IAEA has delivered training in radiotherapy, imaging and SRB/SRS techniques, including stereotactic radiosurgery (SRS) and stereotactic radiotherapy (SRT), to enhance the skills of healthcare professionals across Member States. Moreover, support has been given to conduct feasibility studies to introduce PET/CT and to develop national education and training strategies in nuclear medicine. This comprehensive approach has equipped healthcare professionals with the necessary skills and resources to deliver precise and effective radiation therapy, ensuring high-quality cancer care.

**Achievements and results**

Despite the burden of cancer continues to rise globally, the participation in the TC programme has led to a visible progress in enhancing cancer care in developing Member States.

**Enhanced cancer control planning**. The imPACT Reviews have informed the development and endorsement of National Cancer Control Plans (NCCPs) in numerous Member States. These strategic documents have laid the groundwork for comprehensive cancer control, incorporating the safe and secure use of radiation medicine. This has led to improved availability of evidence, strategies and resources for efficient and effective planning and implementation of cancer control capacity development activities in IAEA Member States.

**Increased access to radiotherapy**. The procurement and installation of advanced radiotherapy equipment have significantly expanded treatment capacities across Member States, including LDCs. Training initiatives have ensured that staff can deliver high-quality care, resulting in an increased number of patients treated in line with relevant guidelines. These efforts have improved the readiness of health systems in providing access to affordable, qualitative, effective and sustainable radiation medicine services within a comprehensive cancer control approach.

**Progress in nuclear medicine.** Delivery of nuclear medicine equipment and training has facilitated the adoption of advanced diagnostic investigations, such as PET/CT. These efforts have improved diagnostic accuracy and expanded treatment options for cancer patients. Delivered capacity is used for disease detection, diagnosis and treatment. Protocols and procedures adopted for the use of nuclear medicine equipment and techniques have enhanced patient care across Member States.

**Impact and perspectives.** The establishment of self-sustainable cancer centres promoted by the IAEA, coupled with continuous support for training and technology maintenance, has contributed to a paradigm shift in the overall landscape of cancer care. This has resulted in increased early detection rates, improved treatment outcomes and a noticeable reduction in cancer mortality rates in regions where the TC programme has intervened. Additionally, the availability of equipment, training and relevant guidelines for cancer diagnosis and treatment, including QA & QC, has further improved comprehensive control, diagnosis and treatment of cancer and other NCDs. These efforts remain vital for tackling the changing difficulties in cancer care and ensuring fair access to quality services and improved health outcomes worldwide.

1. **Nutrition for improved health.**

***Challenges:*** *Limited access to comprehensive nutrition programs, insufficient analytical capacity in isotope techniques, childhood obesity, underdeveloped breastfeeding practices, lack of comprehensive databases for nutrition studies, neglect of malnutrition in government policies, underutilization of stable isotopes in nutrition programs, ineffective national nutrition strategies.*

Recognizing the growing demand from Member States for enhanced nutrition practices, especially among LDCs, the IAEA undertook efforts to address the challenge of limited access to comprehensive nutrition programs and interventions globally. The limited availability of effective nutritional strategies, particularly in underserved areas, posed a significant challenge to global health. In response, the IAEA, through the TC Programme, strategically focused on leveraging isotope techniques and innovative approaches to enhance nutrition for improved health.

**IAEA’s multifaceted approach**

In addressing the challenge of restricted access to comprehensive nutrition programs and interventions, the IAEA has implemented a comprehensive approach through the TC Programme. Beyond the initial implementation, the TC Programme has also enabled a number of support mechanisms such as knowledge transfer between involved regions, allowing successful practices to be shared and adapted. This collaborative learning approach further strengthened efforts of Member States to combat malnutrition.

**Analytical capacity in isotope techniques.** Targeted training to enhance analytical capacity in the use of isotope techniques in nutrition, with a special focus on LDCs, has been delivered through the TC programme. These efforts have included conducting pilot test study procedures, collecting and processing data and saliva samples, and designing databases with ethical approvals obtained.

**Behavioural modification for childhood obesity.** New evidence on the effectiveness of behavioural modification on childhood obesity has been generated. Health and lifestyle guidelines have been revised based on study results, contributing to increased capacity for using stable isotopes to monitor and evaluate changes in body composition post-implementation of obesity behavioural interventions, thereby informing policy decisions across Member States.

**Stable isotopes in nutrition programmes.** The increase of the use of stable isotopes in evaluating the effectiveness of nutrition programs has been facilitated in Member States participating in relevant projects within the TC programme. This has involved training initiatives, delivering equipment and consumables, and supporting laboratories applying isotope techniques.

**Breastfeeding interventions.** New findings regarding the efficacy of breastfeeding interventions for infants up to 2 years old have been produced. The guidelines for infant and young child feeding have been updated, aligning with study outcomes and advocating for optimal feeding practices, with a specific emphasis on exclusive breastfeeding for the initial 6 months.

**Assessment of nutrition program efficacy.** Expert advice on the assessment of efficacy of nutrition programs, interventions, and practices was delivered. This included providing knowledge on the efficacy of interventions and generating new information on the magnitude of risk factors for nutrition-related non-communicable diseases (NCDs).

**Achievements and results**

The TC Programme played a pivotal role in achieving significant improvements in global nutrition programs and practices. The following aspects reflect the spectre of results achieved worldwide with the support from the IAEA.

**National strategies and guidelines.** The IAEA's efforts contributed to the development and revision of national strategies and guidelines. This included improved national strategies on infant and young child nutrition, prevention and control of nutrition-related NCDs, and the treatment of severe acute malnutrition (SAM) children.

**Database development.** Databases on study results were developed, providing critical information for assessing rates of nutrition-related issues in specific populations and age groups using stable isotope techniques.

**Government prioritization.** Assessments of SAM or MAM (moderate malnutrition) children were prioritized in government policies, with national nutrition policies making decisions based on evaluations of nutrition programs, interventions, and practices.

**Impact and perspectives.** The IAEA continues to address the ongoing challenge of limited global access to nutrition programs by leveraging isotope techniques through the TC Programme. Such efforts have led to enhanced national approaches to nutrition in Member States, the development of relevant databases and increased accessibility to programs that focus on assessing and addressing malnutrition. The IAEA continues to promote role of isotope techniques in enhancing global nutrition practices.

1. **Radiological applications in healthcare.**

***Challenges:*** *Limited access to advanced radiopharmaceutical production technologies, inadequate development of quality assurance and quality control protocols in radiopharmaceutical laboratories, insufficient training and expertise in calibration and dosimetry for accurate radiation dosage delivery, lack of comprehensive radiation protection measures in medical applications, limited infrastructure for cyclotron and radioisotope production in healthcare facilities.*

In the early 2000s, the shortage of resources for producing, ensuring quality and using radioisotopes and radiopharmaceuticals, along with the absence of standardized dosimetry and medical physics practices were identified by many Member States as main obstacles in providing optimal healthcare solutions. Among additional challenges were the lack of resources for producing and ensuring the quality of radioisotopes and radiopharmaceuticals as well as shortage in standardized dosimetry and medical physics practices. Addressing these and other health related challenges has become crucial for the IAEA to fulfil its mission of promoting peaceful nuclear energy use and ensuring access to advanced medical technologies worldwide. The TC programme has been used as an efficient framework for delivery of relevant support to Member States.

**IAEA’s multifaceted approach**

In response to the growing need for improved medical services and radiation technology, the IAEA has prioritized efforts to enhance training, infrastructure development and quality assurance in the field of nuclear medicine and radiation oncology. Relevant TC programme projects have extensively addressed pressing global challenges to advance radiological applications in healthcare.

**Radioisotopes and radiopharmaceuticals production**. Training on the production and quality control of radiopharmaceuticals has been delivered by the IAEA, establishing or upgrading cyclotrons and radioisotope production laboratories in interested Member States. The goal was to increase production, adopt good manufacturing practices (GMP) and ensure adherence to relevant protocols.

**Development of QA/QC protocols.** Support has been provided in the development of quality assurance (QA) and quality control (QC) protocols. Training initiatives aimed to establish internationally recognized protocols and procedures, fostering the adoption of QA and QC standards in laboratories producing radiopharmaceuticals.

**Dosimetry and medical physics**. Training in calibration and dosimetry has been delivered through the TC programme, along with the establishment of physical infrastructure, focusing on improving technical skills primarily in medical applications. The aim was to establish national dosimetry standards, apply QA and QC systems, and internationally recognize calibration and measurement capabilities for optimal diagnosis and treatment.

**Radiation protection.** Training in radiation protection for medical applications, including curriculum and program development, has been undertaken to enhance technical skills of professionals in interested Member States. These efforts sought to increase the number of professionals in medical physics, promote the adoption of curricula and training programs and ensure trained personnel apply their skills effectively.

**Achievements and results**

Through strategic initiatives and collaborative efforts in the framework of the TC Programme a number of measures were implemented to enhance the capabilities of Member States in establishment of capacity-building projects aimed at strengthening the technical know-how and infrastructure required for the production of radioisotopes. The IAEA facilitated the transfer of knowledge and technology, fostering a more widespread expertise base among Member States to ensure sustainable and safe practices in the medical application of radioisotopes. Comprehensive training programs have been implemented and guidance provided on the safe utilization of radioisotopes and radiopharmaceuticals. The TC Programme has contributed to the creation of a more interconnected and efficient global network for the distribution of these critical medical resources.

**Increased production and adoption.** Training and support led to an increase in the production and use of radioisotopes and radiopharmaceuticals in medical applications in recipient Member States. The establishment and upgrade of production laboratories contributed to the adoption of GMP, ensuring adherence to relevant protocols.

**Establishment of QA/QC protocols.** Support in developing QA/QC protocols resulted in the establishment of national standards. Numerous laboratories adopted QA and QC practices, ensuring the production of radiopharmaceuticals in accordance with established protocols.

**Improved dosimetry and medical physics.** Training in calibration and dosimetry, along with infrastructure development, enhanced technical skills. National dosimetry standards were established, and QA and QC systems were applied, contributing to improved patient protection and optimal diagnosis and treatment.

**Enhanced radiation protection.** Training in radiation protection led to an increased number of professionals in medical physics. The adoption and dissemination of curricula and training programs ensured that trained personnel effectively applied their technical skills in radiation protection for medical applications.

**Impact and perspectives.** The support provided to Member States through the TC Programme has reshaped global healthcare by increasing the production and use of radioisotopes, establishing rigorous national standards, and advancing dosimetry and medical physics practices. These achievements set the stage for future efforts with an overall goal to ensure progress in healthcare worldwide and especially in LDCs. The TC Programme continues to be a driving force in using nuclear technology for healthcare improvements.

1. **NUCLEAR SAFETY**

Throughout the 21st century, nuclear safety has faced various challenges, including weak regulatory infrastructure, fragmented regulations and limited emergency preparedness across Member States. Recognizing these issues, significant steps have been undertaken within the TC programme to support Member States in overcoming these challenges.

The IAEA has aimed to improve safety by building capacity and working together with Member States. As a result of such cooperation, safety recommendations were developed, guidelines were drafted and standardized safety protocols adopted. By offering training and supplying equipment, the TC programme empowered Member States through their regulatory authorities to enforce safety legislation effectively, enhancing monitoring, enforcement and compliance.

The impact of mentioned collaborative efforts on nuclear safety has been substantial. Regulatory reforms, streamlined frameworks, and enhanced capacities have notably boosted safety standards worldwide. This has resulted in improved compliance, better emergency readiness, and enhanced public health outcomes. Moving forward, continued collaboration and innovation are crucial for maintaining these achievements and ensuring long-term resilience. Through partnerships, the TC programme remains instrumental in advancing nuclear safety practices globally, emphasizing the significance of cooperation in protecting both humanity and the environment in the future nuclear development era.

1. **Governmental and regulatory infrastructure for radiation and nuclear installations safety.**

***Challenges:*** *Inadequate governmental and regulatory infrastructure for radiation safety and nuclear installations security, lack of standardized safety protocols, insufficient capacities for emergency preparedness, fragmented regulatory frameworks across Member States.*

Ensuring nuclear safety of radiation and nuclear installations has emerged as a paramount concern in the 21st century. With the growing utilization of nuclear energy and radiation technology, existing regulatory frameworks have proven inadequate to address the evolving complexities and risks associated with these technologies. Fragmented regulations, coupled with insufficient emergency preparedness and a lack of standardized safety protocols, have underscored the urgent need for cohesive and robust governmental and regulatory infrastructure. The TC programme comprehensively addressed these challenges, aiming to enhance Member States' capacities to safeguard public health and environmental integrity while facilitating the peaceful use of nuclear energy.

**IAEA’s multifaceted approach**

The IAEA has been instrumental in advancing global radiation safety and regulatory frameworks through its extensive support to Member States. The TC programme has offered capacity-building projects and supplying essential equipment. With this contribution the IAEA has empowered regulatory authorities to effectively address a wide range of radiation safety concerns. This support has enabled regulatory bodies to develop and refine safety protocols aligned with international standards, thereby establishing robust governmental and regulatory frameworks that adhere to IAEA safety standards and legal instruments across Member States.

**Support and development of safety protocols.** The IAEA provided extensive support to Member States in drafting safety protocols and regulatory guidelines, facilitating the alignment of their relevant frameworks with international standards. Through capacity-building programs, regulatory authorities have been empowered to draft and refine protocols addressing diverse radiation safety concerns. This approach has resulted in the establishment of robust governmental and regulatory frameworks in member States that harmonized with IAEA safety standards and legal instruments.

**Capacity building and equipment provision.** Recognizing the pivotal role of trained personnel and state-of-the-art equipment in ensuring effective regulatory oversight, the IAEA has focused on capacity-building initiatives. Training programs have equipped personnel with the skills necessary for regulatory infrastructure management in radiation safety. Additionally, critical equipment for monitoring and emergency response has been provided, enhancing the operational capabilities of relevant institutions and government entities. This approach has culminated in a proliferation of trained personnel and well-equipped institutions capable of conducting inspections and ensuring readiness for emergency situations across Member States.

**Achievements and results**

In the field of nuclear safety, the TC programme in the 21st century has focused on issues related to strengthening governmental and regulatory infrastructure for radiation safety and nuclear installations. The IAEA has assisted Member States in implementing standardized safety protocols, providing support through to make regulatory frameworks more robust. Capacity-building initiatives have improved operational capacities, enabling more effective monitoring and emergency response. This effort has empowered Member States to ensure the safe use of nuclear energy and radiation technology, leading to increased compliance and improved public health outcomes. Enhanced governmental and regulatory infrastructures needed to ensure radiation safety for the protection of people and the environment have been established or enhanced as part of this effort.

**Strengthened regulatory frameworks.** Implementation of safety protocols and regulatory guidelines, supported by the IAEA, has led to the establishment of robust governmental and regulatory frameworks in Member States. Enhanced capacities in drafting and implementing safety protocols have ensured alignment with international standards, thereby strengthening regulatory oversight and compliance.

**Enhanced operational capacities.** Through capacity-building initiatives and equipment provision, regulatory bodies in Member States have witnessed a notable enhancement in operational capacities for monitoring, inspection and emergency preparedness. Trained personnel and well-equipped institutions plays a key role in fostering a culture of safety and security, ensuring effective regulatory enforcement and response to potential emergencies.

**Impact and perspectives.** Utilizing the TC programme, Member States have significantly improved safety protocols and enhanced operational capacities, equipping them to ensure the safe use of nuclear energy and radiation technology. This has led to better compliance, increased emergency preparedness and improved public health outcomes. Ongoing collaboration and innovation will be essential to sustain these achievements and promote long-term resilience in nuclear safety worldwide.

1. **Safety of nuclear installations.**

***Challenges:*** *Ensuring adequate safety measures for nuclear installations, including the development of robust regulatory frameworks, operational safety protocols, and emergency preparedness, amid evolving technological advancements and potential risks.*

As the demand for nuclear energy in the 21st century continued to grow, ensuring the safety and security of nuclear installations became increasingly paramount. However, challenges such as the need for updated safety protocols, insufficient regulatory infrastructure and the requirement for improved operational safety persisted. In response to these challenges, the IAEA has focused on updating safety protocols, establishing stronger regulatory frameworks and improving emergency preparedness. Through capacity-building projects and collaboration, the TC programme has aimed to enhance safety across nuclear installations worldwide.

**IAEA’s multifaceted approach**

In response to the escalating demand for nuclear energy in the early 21st century, the TC programme has set a central framework for providing guidance and technical assistance to ensure safety of nuclear installations across Member States. The imperative need for robust regulatory frameworks, operational safety protocols and emergency preparedness has been reflected in collaborative efforts and capacity-building initiatives implemented through the TC programme on a national and regional levels. This approach underscores the central role of the IAEA in promoting global nuclear safety standards and fostering cooperation among Member States.

**Strengthening safety infrastructure.** Through the TC programme extensive support has been provided in the development and updating of safety recommendations and plans for nuclear installations. Draft recommendations and plans have been formulated, addressing various aspects of reactor safety and accident prevention. Furthermore, the IAEA has facilitated the adoption and implementation of these recommendations and plans, contributing to improvements in operational safety and the control of safety-related activities.

**Enhancing regulatory oversight.** Recognizing the importance of regulatory control in ensuring nuclear safety, the IAEA has conducted training programs on regulatory approaches in safety assessment. These programs have aimed to develop human capacity in regulatory frameworks, equipping regulatory authorities with the necessary skills to conduct safety assessments effectively. As a result, institutions across Member States have been empowered to carry out safety assessments, leading to enhanced operational safety and improved capacity utilization.

**Achievements and results**

The development of nuclear safety in the 21st century is characterized by dynamic changes and strategic reactions to emerging challenges on a global scale. The TC programme has served as a driving force in shaping trends towards enhanced safety standards focusing on strengthening regulatory infrastructure and fostering capacity development in safety assessment. The TC programme has addressed immediate challenges and laid the groundwork for sustained advancements in nuclear safety practices.

**Enhanced regulatory infrastructure.** Main focus of the TC programme in the field of nuclear safety in the 21st century has been placed on the development and enhancement of regulatory infrastructure. With IAEA's support in drafting recommendations and plans, regulatory frameworks have been strengthened, ensuring compliance with international safety standards. These collaborative efforts have resulted in improved operational safety and enhanced control of safety-related activities, thereby safeguarding the environment and public health.

**Capacity development in safety assessment.** Through training programs on regulatory approaches in safety assessment, the TC programme has fostered the establishment of human capacity in safety assessment methodologies. Member States’ institutions equipped with these skills have conducted safety assessments, contributing to a better understanding of safety risks and the implementation of effective safety measures. Safety assessments have become integral in decision-making processes, ensuring continuous improvements in nuclear safety worldwide.

**Impact and perspectives.** The TC programme has had a profound impact on nuclear safety in the 21st century, focusing on strengthening regulatory infrastructure and fostering capacity development in safety assessment. These efforts have led to concrete improvements, such as better compliance with global safety standards and improved safety management in Member States. The TC programme’s impact extends beyond immediate achievements, as it sets the stage for continued progress and fosters a culture of safety within the nuclear industry globally.

1. **Radiation protection of workers and the public**

***Challenges:*** *Inadequate safety infrastructure and lack of standardized safety protocols, under-recognition of the importance of radiation protection training and education, limited capacities for emergency preparedness, fragmented regulatory frameworks across Member States.*

The radiation technology continued to expand exponentially in the 21st century, making the necessity for robust radiation protection measures for workers and the public increasingly critical. Alongside the technological advancements, a greater need to protect workers and the public from its risks has emerged. Ensuring comprehensive radiation protection measures has become paramount to mitigate these risks and uphold safety standards across industries. In this context, the framework established by the TC programme, has been instrumental in promoting global cooperation, setting standards and providing technical assistance to enhance radiation protection measures in Member States.

**IAEA’s multifaceted approach**

The IAEA has always been at the forefront of efforts to enhance radiation protection for workers and the public. In addition to this longstanding commitment, the TC programme in the 21st century has prioritized the equipping of personnel with essential skills and knowledge, alongside the establishment of standardized systems for radiation protection. These efforts reflect the Agency's dedication to ensuring the highest standards of safety and protection in the field of radiation, ultimately contributing to the well-being of workers and the broader public.

**Enhancing occupational radiation protection capacities.** The IAEA has delivered comprehensive training programs in occupational radiation protection, aiming to equip personnel with the necessary skills and knowledge to adhere to recognized standards. Through these programs, staff have been trained to effectively monitor and manage radiation exposure, contributing to a reduction in work-related incidences of radiation exposure.

**Establishing quality management protocols.** Recognizing the importance of quality management in radiation protection, the IAEA has drafted quality management protocols for the monitoring and management of radiation exposure. These protocols ensure the implementation of standardized systems for radiation protection, enhancing the effectiveness of radiation safety measures.

**Facilitating physical infrastructure and equipment provision.** The IAEA has provided physical infrastructure and equipment for dosimetry and occupational radiation protection, enabling the implementation of quality guidelines for monitoring and managing radiation exposure. By facilitating the utilization of state-of-the-art equipment and infrastructure, the IAEA has ensured the effective protection of workers and the public from radiation hazards.

**Achievements and results**

With a TC programme’s focus placed on enhancing adherence to radiation protection standards and implementing quality management systems, the IAEA has effectively countered inadequacies in safety infrastructure and standardized protocols worldwide. Improved consistency and reliability in radiation safety practices effectively mitigate risks associated with radiation exposure. Building upon these achievements, further efforts within the TC programme are directed towards enhancing global collaboration and knowledge-sharing initiatives. Ongoing cooperation with Member States in this regard helps to identify emerging challenges and areas for refinement, ensuring that radiation protection standards remain robust and responsive to evolving needs and advancements in technology.

**Enhanced adherence to radiation protection standards.** The IAEA's training programs have resulted in improved adherence to recognized standards in occupational radiation protection. Staff trained by the IAEA demonstrate enhanced competency in monitoring and managing radiation exposure, leading to a reduction in work-related incidences of radiation exposure.

**Implementation of quality management systems.** The establishment of quality management protocols with support from the IAEA has led to the implementation of standardized systems for monitoring and managing radiation exposure in Member States. These protocols ensure the utilization of quality guidelines for radiation protection, resulting in improved data generation and utilization of equipment and infrastructure for dosimetry and radiation protection.

**Impact and perspectives.** One of the TC programme's tasks in the early 2000s was to assist Member States in reshaping the landscape of nuclear safety, particularly in addressing the challenges posed by inadequate safety infrastructure and lack of standardized safety protocols. From a perspective point, the TC programme continues to ensure that safety remains a top priority, fostering a culture of safety within the nuclear industry worldwide.

1. **Transport safety.**

***Challenges:*** *Inconsistencies in safety regulations, inadequate implementation of transport safety protocols, limited capacities for emergency preparedness.*

The evolving landscape of radioactive material transport in the 21st century has highlighted the critical importance of robust safety measures. However, varying safety regulations, coupled with inadequate implementation and emergency preparedness, created vulnerabilities in ensuring the safe transport of radioactive materials. Addressing these challenges required close cooperation between IAEA and Member States to enhance transport safety protocols, streamline regulatory frameworks, and bolster emergency response capacities. The TC programme has served as a vital platform for fostering global collaboration, setting standards, and providing technical assistance to enhance transport safety measures worldwide.

**IAEA’s multifaceted approach**

Focusing on regulatory development and capacity-building initiatives, the IAEA aimed to address inconsistencies in safety regulations, improve the implementation of transport safety protocols, and strengthen emergency preparedness capabilities. Collaborative efforts were facilitated within the TC programme to develop draft recommendations for regulatory changes, targeting key areas of transport safety protocols to standardize safety measures and streamline regulatory frameworks.

**Development of regulations on transport safety.** The IAEA has provided extensive support in developing draft recommendations for regulatory changes to enhance transport safety. Through collaborative efforts, recommendations for regulatory changes have been developed, addressing key aspects of transport safety protocols. These recommendations aim to standardize safety measures, streamline regulatory frameworks, and improve the overall safety of radioactive material transport.

**Training on the implementation of regulations.** Recognizing the importance of capacity-building, the IAEA has conducted training programs on the implementation of transport safety regulations. These programs aim to strengthen the capacities of regulatory authorities and institutions responsible for overseeing transport safety. By providing training to personnel, the IAEA enhances their ability to effectively implement and enforce transport safety legislation, thereby mitigating risks associated with radioactive material transport.

**Achievements and results**

The TC programme in the 21st century has extensively addressed the issues of regulatory inconsistencies, safety protocol gaps and limited emergency preparedness. The adoption of regulatory recommendations has led to significant improvements in transport safety standards across Member States. These reforms have streamlined regulatory frameworks, making them more efficient and coherent. As a result, there has been a notable enhancement in overall compliance with international transport safety standards, reducing the likelihood of safety breaches and incidents during the transportation of radioactive materials.

**Adoption of regulatory recommendations.** The IAEA's support in developing recommendations for regulatory changes has led to the adoption of key regulatory reforms across Member States. These reforms have streamlined regulatory frameworks, standardized safety protocols, and improved overall compliance with international transport safety standards.

**Strengthening regulatory capacities.** Through capacity-building initiatives implemented under the TC programme, the IAEA has strengthened the capacities of regulatory authorities and institutions responsible for overseeing transport safety. This enhanced capacity has facilitated the effective implementation of transport safety legislation, leading to improved monitoring, enforcement, and compliance with safety protocols.

**Impact and perspectives.** Through collaborative efforts and technical assistance, the IAEA has addressed longstanding challenges and facilitated the implementation of comprehensive safety measures across Member States. The sustainability of these results depends on the continued commitment of all parties to maintaining and further advancing transport safety initiatives. The TC programme lays the foundation for sustained improvements in transport safety and the safe and secure transport of radioactive materials worldwide.

1. **Radiation protection in medical uses of ionizing radiation.**

***Challenges:*** *Inadequate optimization of patient protection, lack of sufficient radiation safety measures for healthcare workers, variability in protocols and guidelines for radiation protection in medical facilities, improper disposal and management of radioactive waste generated during medical procedures.*

With the continuous advancement of medical technologies involving radiation in the 21st century, the imperative for robust radiation protection measures for both healthcare workers and patients has become increasingly evident. In response to this urgent need, the TC programme has played a key role in developing specific plans to improve patient protection, boost safety for healthcare workers, standardize guidelines in medical facilities and manage radioactive waste from medical procedures more effectively. The IAEA has comprehensively addressed identified challenges through collaborative efforts with Member States and provision of technical assistance.

**IAEA’s multifaceted approach**

The 21st century TC programme's initiatives in radiation protection for medical uses of ionizing radiation operated on a vast scale, extending well beyond mere equipment provision. These initiatives encompassed comprehensive training, establishment of standardized protocols, and implementation of quality management systems. This approach ensured global coverage, equipping healthcare workers in involved Member States with essential skills and knowledge.

**Enhancing radiation protection training and education.** Responding to growing demands of Member States the IAEA through the TC programme has prioritized comprehensive training programs aimed at providing healthcare personnel with crucial expertise in radiation protection. Relevant projects focused on promoting adherence to recognized standards and best practices in radiation safety protocols.

**Establishing quality management systems.** Recognizing the significance of quality management in radiation protection, the IAEA has developed protocols for monitoring and managing radiation exposure. These standardized systems were implemented in interested Member States and now ensure the effective implementation of safety measures and enhance the overall reliability of radiation safety practices in medical settings.

**Facilitating provision of physical infrastructure and equipment.** Through the provision of essential infrastructure and equipment for dosimetry and radiation protection, the IAEA enabled medical institutions to adhere to quality guidelines and effectively manage radiation exposure. State-of-the-art equipment and infrastructure facilitate the implementation of standardized safety measures, ensuring the protection of both healthcare workers and patients.

**Achievements and results**

Through the TC programme, significant progress has been made in the 21st century in improving radiation protection in medical uses of ionizing radiation across Member States. As a result of these efforts, healthcare workers demonstrate improved compliance with radiation protection standards, leading to a tangible decrease in incidents of radiation exposure. The implementation of standardized protocols ensures better monitoring and management of radiation exposure in medical settings.

**Improved compliance with recognized standards in radiation protection.** Training programs facilitated by the IAEA have resulted in improved compliance with recognized standards in radiation protection among healthcare personnel. This has led to a reduction in instances of radiation exposure incidents during medical procedures.

**Adoption of effective systems for monitoring and managing radiation exposure.** The establishment of standardized quality management protocols supported by the IAEA has led to the widespread adoption of effective systems for monitoring and managing radiation exposure in medical institutions. This has resulted in improved data generation and utilization of equipment and infrastructure for radiation protection.

**Impact and perspectives.** The IAEA has been instrumental in addressing challenges in the field of radiation protection for medical uses of ionizing radiation. The TC programme enabled Member States to access tailored strategies and technical assistance to address specific gaps, such as inadequate patient protection and variability in safety protocols. Engagement in the TC programme fosters a culture of collaboration and knowledge-sharing among Member States, it offers practical tools and collaborative opportunities to address existing challenges and improve radiation protection in medical uses of ionizing radiation.

1. **Radioactive waste management, decommissioning and remediation of contaminated sites.**

***Challenges:*** *Weak infrastructure for radioactive waste management, insufficient technical expertise in handling, environmental contamination, inadequate regulatory compliance hindering progress, limited public engagement and stakeholder participation.*

The management of radioactive waste, environmental protection, and the decommissioning of nuclear facilities represent critical challenges in the realm of nuclear energy. With the increasing use of nuclear technology worldwide, there is a growing need for effective strategies to handle radioactive materials and mitigate potential environmental risks. Concerns surrounding the safe storage, monitoring, and disposal of radioactive waste, as well as the remediation of contaminated sites, have garnered significant attention from international organizations and regulatory bodies. In this context, the IAEA plays a pivotal role in providing guidance, expertise and technical assistance to Member States in navigating these challenges.

**IAEA’s multifaceted approach**

The IAEA stands at the forefront of addressing critical challenges in the field of nuclear energy management. The significance of the TC programme lies in its indispensable role in providing essential resources, expertise and guidance to Member States in overcoming obstacles related to equipment provision, site selection, nuclear materials storage and decommissioning of nuclear facilities. By facilitating cooperation and knowledge-sharing among nations, the TC programme in the 21st century has played a crucial part in advancing global efforts to ensure the safe and sustainable use of nuclear technology while mitigating environmental risks.

**Equipment provision and training.** The TC programme has equipped Member States with essential tools and provided comprehensive training to effectively monitor environmental radiation, ensuring the safety of surrounding areas.

**Site selection support.** Through the TC programme, Member States have received support including recommendations in selecting appropriate sites for the disposal of radioactive waste, aiming to minimize environmental impact.

**Guidance on nuclear materials storage:** The TC programme has furnished guidance on the safe storage of nuclear materials, mitigating risks associated with improper handling and storage practices.

**Training and technical support for decommissioning.** Recognizing the complexities involved in decommissioning nuclear facilities, the TC programme has provided training and technical assistance to Member States, facilitating a safe and efficient decommissioning process.

**Achievements and results**

The importance of the TC programme lies in its transformative impact, efficiency and global significance for enhancing safety standards and fostering sustainable practices in the nuclear energy sector. From enhanced capacities in environmental monitoring and site selection to improved capabilities in nuclear storage and decommissioning planning, the TC programme in the 21st century has played a pivotal role in empowering Member States in overcoming challenges related to radioactive waste management, decommissioning and remediation of contaminated sites.

**Enhanced capacities in environmental monitoring and site selection.** Member States have benefited from enhanced capacities in environmental radiation monitoring and site selection processes, achieved through participation in the TC programme. They have been provided with advanced equipment and comprehensive training, ensuring the production of accurate environmental monitoring information and the identification of sites in conformity with quality and safety standards. Moreover, IAEA support and recommendations have been actively utilized in decision-making processes, further enhancing the effectiveness and reliability of site selection procedures.

**Improved capacities in nuclear storage and decommissioning planning.** Significant steps have been made in enhancing capacities for the storage of nuclear materials and the development of decommissioning plans through the TC programme. With guidance provided by the IAEA, Member States have adopted protocols and procedures to store radioactive materials in accordance with safety standards and guidelines. Additionally, effective decommissioning plans, developed with IAEA support, have ensured the safe and efficient transition of nuclear facilities from operation to decommissioning phase, thereby improving sustainable management of radioactive waste and adhering to safety guidelines.

**Initiation of management, decommissioning or remediation actions.** Management, decommissioning or remediation actions have been initiated in interested Member States based on improved capacities and IAEA support. These actions have adhered to safety standards and guidelines, thereby safeguarding public health and the environment.

**Impact and perspectives.** The enhanced capacities in environmental monitoring and site selection, facilitated by the TC programme and IAEA support, have resulted in significant improvements in the management of radioactive materials. Member States now possess the tools and knowledge to accurately monitor environmental radiation levels and select suitable sites for radioactive waste disposal, ensuring enhanced safety and compliance with quality standards. These efforts are imperative for continued progress in radioactive waste management and environmental protection. By leveraging the expertise and support provided by the IAEA through the TC programme, Member States can build upon their strengthened capacities to address emerging challenges and sustainably manage radioactive materials.

1. **INDUSTRIAL APPLICATIONS**

In the dynamic landscape of the 21st century, the usage of nuclear technology in various industrial applications has experienced significant growth and diversification. From reference products for science and trade to research reactors and radioisotopes in industrial, healthcare, and environmental sectors, nuclear technology has become integral to numerous fields. However, amidst these advancements, several challenges have emerged. They include limited availability of dependable reference products, inadequate infrastructure for safe research reactor operation, and the imperative for comprehensive training and regulatory compliance.

To address these challenges, the TC programme has encompassed a range of activities aimed at enhancing safety, efficiency, and sustainability in the utilization of nuclear technology in industrial applications. IAEA efforts have focused on equipping professionals with essential skills, modernizing infrastructure, and implementing robust regulatory frameworks. The IAEA has facilitated the responsible and sustainable utilization of nuclear technology, ensuring that Member States can maximize its potential effectively.

Improved safety measures in nuclear sites, adoption of cleaner industrial processes, advancements in healthcare diagnostics, and enhanced environmental monitoring efforts are among the notable outcomes. These achievements reflect the effectiveness of the TC programme in addressing the identified challenges and delivering tangible benefits to Member States. Through the framework established by the TC programme, the IAEA has demonstrated its commitment to enhancing safety, innovation and sustainability in the utilization of nuclear technology across diverse industrial sectors.

1. **Reference products for science and trade.**

***Challenges:*** *Limited availability of dependable reference products for science and trade, limited analytical expertise, outdated laboratory infrastructure, lack of standardized operational protocols, insufficient quality control measures.*

During the 21st century the rising demand for precise reference products in science and trade as well as the necessity for robust analytical expertise and quality assurance measures became more apparent. However, challenges such as the need for enhanced analytical capabilities, standardized operational protocols, and reliable quality control persisted. In response to these challenges, the IAEA focused on developing comprehensive training programs, upgrading laboratory infrastructure and facilitating the production of reference products. Through capacity-building efforts, the TC programme in the 21st century has aimed to enhance the availability and reliability of reference products for science and trade worldwide.

**IAEA’s multifaceted approach**

In the dynamic landscape of the 21st century, the demand for reliable reference products across scientific, industrial, cultural and trade sectors have grown exponentially. The nature of projects undertaken through the TC programme in this context varied from comprehensive training programs aimed at enhancing analytical capabilities to capacity-building initiatives focused on modernizing laboratory infrastructure. The foundation laid by the TC programme has empowered Member States to enhance analytical capabilities, modernize infrastructure and implement quality assurance, ensuring reliable reference products vital for global decision-making and cultural preservation.

**Enhancing analytical expertise.** The IAEA has provided extensive support in the development and delivery of training programs aimed at enhancing analytical expertise for the production of reference products. Thus, training curricula have been developed, addressing various aspects of analytical techniques and quality assurance measures. Furthermore, the adoption and implementation of these training programs have been facilitated though the TC programme, contributing to improvements in analytical capabilities and the production of reliable reference materials across various fields.

**Upgrading laboratory infrastructure.** Recognizing the importance of modern laboratory infrastructure in ensuring the quality and reliability of reference products, the TC programme has included capacity-building projects on laboratory upgrading and equipment procurement. These projects have aimed to enhance laboratory infrastructure and equipment for the production and testing of reference products. As a result, laboratories have been empowered to meet international standards and produce reference materials that meet the needs of various scientific and industrial applications.

**Facilitating production of reference products.** In addition to capacity-building initiatives, the IAEA has supported Member States in the production of reference products through technical assistance and guidance. This support has included the development of operational protocols, quality assurance measures and best practices for the production and certification of reference materials. By implementing TC projects related to the production of reliable reference products, the IAEA has contributed to evidence-based decision-making, quality assurance and cultural heritage preservation efforts in Member States.

**Achievements and results**

Significant achievements have been realized through the TC programme in the 21st century. They include enhanced cultural heritage understanding, improved quality and reliability of nuclear analytical techniques as well as seamless integration of laboratories into environmental monitoring networks. These results reflect the commitment to excellence and the practical role of the TC programme in facilitating advancements in reference product development.

**Enhanced analytical expertise.** The focus of the TC programme in the field of reference product development in the 21st century has been placed on comprehensive training programs. With the support of the IAEA, analytical capabilities have been improved, ensuring the production of reliable reference materials that meet international standards. These collaborative efforts have resulted in improved quality and reliability of reference products, thereby enhancing their utility in various scientific, industrial and cultural heritage applications.

**Upgraded laboratory infrastructure.** Through capacity-building projects and equipment procurement support, the IAEA has facilitated the upgrading of laboratory infrastructure for reference product development. Laboratories equipped with modern infrastructure and state-of-the-art equipment have been able to produce reference materials that meet international quality standards. As a result, the availability and reliability of reference products for science, trade and cultural heritage preservation have been enhanced, contributing to evidence-based decision-making, quality assurance and cultural heritage preservation.

**Enhanced production of reference products.** In addition to capacity-building efforts, the IAEA has provided technical assistance and guidance to Member States in the production of reference products. This support has included the development of operational protocols, quality assurance measures and best practices for the production and certification of reference materials.

**Impact and perspectives.** Results achieved through participation in the TC programme offer Member States invaluable tools for improvements in the fields of science and trade. These enhancements enable more accurate scientific research, evidence-based decision-making and effective environmental monitoring. By leveraging these capabilities Member States receive solid instruments to better preserve cultural heritage, improve public health and safety and safeguard the environment for prosperous future.

1. **Research reactors.**

***Challenges:*** *Inadequate infrastructure, training and compliance hindering safe research reactor operation, need for emergency response plans improvement, limited international collaboration for knowledge sharing.*

As in the case of any other nuclear technology, the establishment of new or development of existing research reactors required extensive exploration, industrial progress and educational advancement. These reactors have also faced various challenges, including the need for enhanced operational safety, regulatory compliance and technological innovation. Addressing these challenges required a comprehensive strategy, and the TC programme has been at the forefront of responding to them in the 21st century. Through targeted training initiatives, strengthening safety protocols and fostering innovation, the TC programme has aimed to provide Member States with the necessary expertise to maximize the potential of research reactors effectively.

**IAEA’s multifaceted approach**

The 21st century challenges associated with research reactors have been comprehensively addressed through the TC programme. The main focus has been put on operation, safety and innovation. Through comprehensive training initiatives, the TC programme has aimed to equip professionals with essential skills in reactor capacity, fuel management and infrastructure development.

**Capacity building through training initiatives.** The TC programme has conducted extensive training on research reactor capacity, spent fuel management, and infrastructure development. This equips professionals with the necessary expertise to operate and maintain research reactors safely and efficiently.

**Enhancing operational safety and fuel management.** Capacity in spent fuel management and reactor safety testing has been strengthened through training and technical assistance. This ensures secure fuel cycles and processes, crucial for the safe operation of research reactors.

**Promoting innovation through operational results.** Operational decisions are now informed by the capacity in fuel management and reactor safety testing. These results foster improved research, development and innovation in various industrial sectors, supported by reliable and secure research reactor operations.

**Achievements and results**

In the domain of nuclear technology, research reactors stand as vital tools for scientific inquiry, industrial innovation and educational advancement. The TC programme in the 21st century has served as a cornerstone in enhancing the capabilities of Member States to develop the potential of research reactors effectively. As nations continue to recognize the strategic importance of research reactors in driving scientific progress and industrial development, the TC programme's role is to facilitate collaboration, knowledge exchange and the sustainable utilization of nuclear technology. The tangible outcomes achieved through the TC programme in the 21st century exemplify its instrumental role in enhancing research reactor capacity, safety and regulatory frameworks worldwide.

**Establishment of new reactor capacity.** As a result of the participation in the TC programme, new or extended reactor capacity has been established in many Member States in the 21st century. These reactors generate operational results in support of diverse industrial applications, contributing to technological advancement and innovation.

**Recommendations for lifetime extension and planning.** Recommendations for planning and capacity building for lifetime extension have been issued, leading to the extension of lifetimes in a number of Member States operating research reactors. This ensures continued support for industrial applications while maintaining safety and efficiency.

**Regulatory support and policy development.** The IAEA's support in developing regulatory regimes, strategies and policies for research reactor development has enhanced the capacity for safe and secure management and operation. Regulatory regimes and strategies are implemented to facilitate informed decision-making on the establishment of research reactors for industrial applications.

**Impact and perspectives.** Participation in the TC programme has led to major progress in research reactors, providing Member States with essential tools for scientific research, industrial innovation and nuclear education. Member States have enhanced their capabilities in operating research reactors safely and efficiently through capacity building, training initiatives and regulatory support. As research reactors continue to be established and utilized worldwide, reflecting an ongoing trend in many countries, further collaboration and knowledge-sharing facilitated by the IAEA will be essential to sustain these achievements. This trend also shows a continued interest in nuclear technology and its applications across various fields, with countries investing in research reactor infrastructure to support scientific advancements, industrial innovation and education in nuclear-related disciplines.

1. **Radioisotopes and radiation technology for industrial, healthcare and environmental applications.**

***Challenges:*** *Lack of comprehensive training, technological advancements and regulatory compliance in the utilization of radioisotopes and radiation technology across various sectors, inadequate expertise among professionals, insufficient safety protocols, lack of standardized practices.*

In the 21st century, the spectrum of applications for radioisotopes and radiation technology has expanded tremendously, encompassing a broad array of sectors. From its traditional roles in industrial processes to healthcare diagnostics and environmental monitoring, the utilization of radioisotopes and radiation technology has evolved and diversified significantly. Similar to research reactors, the utilization of radioisotopes and radiation technology required meticulous training, technological advancements and regulatory compliance. The challenges associated with these applications have been comprehensively addressed the TC programme.

**IAEA’s multifaceted approach**

In order to overcome identified challenges comprehensive, the TC programme proposed a number of projects tailored to the specific needs of professionals in interested Member States. These projects were focused on imparting practical skills, enhancing safety protocols and ensuring regulatory compliance. The TC programme has fostered technological advancements and innovation through research and development initiatives which addressed gaps in existing practices and facilitated the adoption of cutting-edge technologies, thus improving efficiency and effectiveness. Further steps have referred to establishing standardized practices and protocols to ensure consistency and efficiency across sectors, promoting safe and effective utilization of radioisotopes and radiation technology. The TC programme diligently addressed these key areas facilitating the responsible and sustainable application of these technologies by stakeholders across diverse sectors.

**Capacity building and training initiatives.** The TC programme has created a unique framework for extensive training on the use of radioisotopes and radiation technology in various applications, including environmental monitoring, industrial processes, and healthcare diagnostics. This training equips professionals with the necessary expertise to handle radioisotopes safely, conduct precise measurements and interpret data accurately, thus ensuring the efficient and reliable application of these technologies.

**Enhancing safety and efficiency.** Capacity in safety protocols and efficiency gains through the use of radioisotopes and radiation technology has been strengthened through training and technical assistance provided within the TC programme. Such efforts ensured that industrial processes, healthcare procedures and environmental monitoring activities were conducted with the utmost safety and efficiency, mitigating potential risks.

**Promoting innovation and technological advancement.** Operational decisions in utilizing radioisotopes and radiation technology were supplemented by the capacity in safety protocols and efficiency gains. With this approach the TC programme has aimed at improving industrial processes, healthcare diagnostics and environmental monitoring.

**Achievements and results**

The efforts within the TC programme have led to significant improvements in various sectors in the 21st century. Firstly, nuclear sites now have better safety measures, protecting both workers and the public. Secondly, industries have adopted cleaner and safer processes, reducing environmental impact and improving productivity. Thirdly, advancements in healthcare diagnostics have enhanced patient care and safety. Additionally, environmental monitoring has improved, leading to better decision-making and pollution reduction. Overall, these achievements demonstrate the positive impact of the TC programme on safety, innovation, and sustainability.

**Improved safety and security in nuclear sites.** Through enhanced training and safety protocols, Member States have reported improved safety and security measures in nuclear sites where radioisotopes and radiation technology are utilized. The TC programme has contributed to stricter adherence to safety guidelines, improved emergency response plans, and better management of radioactive materials, ensuring the protection of workers and the public in Member States.

**Cleaner and safer industrial processes and infrastructure.** Capacity building initiatives conducted through the TC programme have led to the adoption of cleaner and safer industrial processes and infrastructure utilizing radioisotopes and radiation technology. This has resulted in reduced environmental impact, minimized radiation exposure for workers as well as improved overall efficiency and productivity in industrial operations.

**Enhanced healthcare diagnostics and medical product development.** Training and technical assistance provided by the TC programme have facilitated the development of advanced healthcare diagnostics and medical products utilizing radioisotopes and radiation technology. They include improved diagnostic imaging techniques, more precise radiation therapy treatments and the development of medical products adhering to rigorous standards in clinical safety and quality.

**Environmental monitoring and pollution reduction.** Capacity building efforts have resulted in increased capacities for environmental monitoring and pollution reduction using radioisotopes and radiation technology. Member States have witnessed enhanced capabilities in generating environmental data, implementing strategies to reduce pollutants and utilizing radiation technology for precise measurements in environmental monitoring. The overall achievement has led to improved decision-making and environmental management.

**Impact and perspectives.** The TC programme has contributed to significant improvements in various sectors utilizing radioisotopes and radiation technology. Enhanced safety and security measures in nuclear sites ensure the protection of workers and the public, reducing the risk of accidents and potential radiation exposure. This fosters a safer working environment and builds confidence in surrounding communities. Other achievements include improved patient care and safety, leading to better health outcomes and enhanced quality of life. The relevant perspectives of the TC programme include sharing knowledge, organizing workshops and partnering with industry to drive innovation in radioisotopes and radiation technology.

1. **WATER and the ENVIRONMENT**

The need for effective water resource management is paramount for ensuring the sustainability of ecosystems, particularly in regions with severe climate conditions. However, the management of water resources has always been increasingly challenging due to various factors, including climate change, population growth and pollution. The main challenges in the 21st century rest with inadequate characterization of freshwater aquifers, limited capacity for water quality analysis and ineffective management strategies. Additionally, the limited capacity for water quality analysis has impeded the accurate assessment of pollutant levels and their impacts on ecosystems and human health.

The TC programme has played a crucial role in assisting Member States in enhancing their capacity for water resource management. The scope and substance of the TC programme projects related to water resources management has continuously evolved to respond to the demands and relevant needs of Member States. Through ongoing collaboration and feedback mechanisms, the TC programme ensures that its interventions align with the evolving needs of Member States, enabling them to address current and future water management challenges effectively.

The impact of the TC programme extends beyond individual projects, contributing to long-term sustainability and resilience in water resource management worldwide. It focuses on promoting collaboration between stakeholders and sectors, laying the foundation for evidence-based water management strategies and actions on national, regional and interregional levels. As Member States continue to build upon these achievements, the TC programme remains a vital framework for addressing current and future water management challenges effectively.

1. **Water resources management.**

***Challenges:*** *Inadequate characterization of freshwater aquifers and basins in regions with severe climate conditions, lack of skilled professionals equipped with the necessary expertise to conduct hydrogeological mapping and interpreting isotope hydrology data, limited capacities for water quality analysis and implementing targeted remediation strategies.*

Management of water resources in the 21st century has been confronted with increasingly complex challenges, ranging from water scarcity to pollution. In regions with severe climate circumstances where water shortage or extreme weather events are prevalent, effective water management becomes even more critical for mitigating the impacts of climate change, preserving biodiversity, and safeguarding the health and livelihoods of communities reliant on water resources. The TC programme has played a pivotal role in addressing these challenges by providing targeted assistance through capacity-building projects to enhance water resource management globally. Through expert advice, training, and the provision of advanced technologies such as isotope hydrology, the TC programme has empowered Member States to improve aquifer characterization, implement pollution monitoring systems and develop integrated management strategies.

**IAEA’s multifaceted approach**

The TC programme has demonstrated remarkable practicality and utility in addressing the challenges related to water resource management in the 21st century. First of all, it has provided tangible solutions with an emphasis on capacity-building in Member States. Equipping professionals with essential skills and facilitating infrastructure development has proved to be an effective sustainable strategy for overcoming real-world water-resource challenges. TC programme projects on water resource management are readily applicable in diverse contexts, making a significant difference in addressing water scarcity, pollution, and other pressing issues.

**Characterization of freshwater aquifers.** Expert advice and hydrogeological mapping provided by the TC programme to interested Member States have facilitated the characterization of freshwater aquifers and basins. This has led to increased understanding of aquifer characteristics, including groundwater flow patterns, recharge rates and water quality parameters, enabling evidence-based water management strategies and actions.

**Training and infrastructure for isotope hydrology.** The TC programme has enabled extensive training on isotope hydrology, equipping professionals with the necessary skills to utilize isotopic techniques for water resources management. Additionally, infrastructure development projects have enhanced capacities for isotope hydrology analysis, monitoring and interpretation, thereby improving the accuracy and reliability of water resource assessments.

**Diagnosis and testing of water quality.** Through a number of projects dedicated to diagnosis and testing of water and beverages, capacities for water quality analysis have been established in member States, enabling the identification of contaminants and pollutants. Results from these analyses are used to inform water sourcing, management and control plans, leading to the reduction of contaminant concentrations and the improvement of water quality for consumption.

**Analysis and pollutant mapping.** The TC programme has supported Member States in the analysis and mapping of pollutants in industrial, mining and landfill sites, providing valuable insights for site remediation and water source selection. By generating plans based on mapping and analysis results, may Member States have enhanced their capabilities to effectively address pollution issues and safeguard water resources.

**Achievements and results**

Effective water resource management is crucial for sustaining ecosystems, supporting agriculture, and ensuring access to safe drinking water, particularly in regions facing severe climate conditions. The TC programme has empowered Member States to effectively manage their water resources, with a special focus on countries prone to water scarcity. The impact of the TC programme becomes even more important in the face of evolving climate-related challenges.

**Improved quality and sustainability of freshwater systems.** The TC programme created a framework for expert advice, training and infrastructure development. With support from the IAEA, Member States have enhanced their capacity to manage freshwater resources effectively. This has resulted in evidence-based water management strategies, improved water quality and sustainable land and water management practices, ensuring the long-term viability of freshwater ecosystems.

**Enhanced pollution monitoring and remediation.** Capacity building initiatives in isotope hydrology and water quality analysis have enabled Member States to monitor and remediate pollution effectively. Projects dedicated to diagnosing water quality issues and mapping pollutants have enabled participating Member States to implement targeted remediation strategies, leading to the reduction of contaminant concentrations and the restoration of water quality.

**Integrated water management.** The TC programme has supported the development and implementation of integrated water management plans worldwide, promoting collaboration between stakeholders and sectors. Integrating land and water management practices has enabled Member States to optimize water use, minimize pollution, and sustainably manage freshwater resources for future generations.

**Impact and perspectives.** The visible transformation from inadequate to improved water resource management in Member States facing relevant challenges has been driven by the concerted efforts of the TC programme. Despite significant progress, ongoing challenges such as water scarcity, pollution and the need for sustainable practices persist requiring further attention and support. As Member States needs in this field continue to grow, the impact of the TC programme will continue to adapt, ensuring its ongoing significance in global efforts to safeguard water resources.

1. **Marine, terrestrial and coastal environments.**

***Challenges:*** *Lack of effective management strategies, environmental degradation and vulnerability of biodiversity.*

At the dawn of the 21st century, ecosystems faced a myriad of challenges, ranging from pollution and habitat destruction to climate change and biodiversity loss. These challenges arise from various human activities such as industrialization, urbanization, overfishing and deforestation. The TC programme has been instrumental in addressing them by providing Member States with the necessary expertise, training and resources to implement effective management strategies and conservation measures. While achieved results have led to enhanced resilience and sustainability of these vital ecosystems for future generations, many challenges remain unresolved. Nevertheless, the TC programme remains an effective framework, providing Member States with the necessary tools and expertise to address environmental issues effectively.

**IAEA’s multifaceted approach**

Through comprehensive support initiatives, the IAEA has facilitated the development and implementation of pollution clean-up strategies across diverse environments, spanning from land and air to marine and coastal ecosystems. TC programme projects focused on strengthening the monitoring capacity for environmental factors critical to ecosystem health. The main goal was to enhance Member States ability to assess and mitigate the impact of environmental pollutants and climate change, thereby contributing to the sustainable management of marine, terrestrial, and coastal environments.

**Empowering environmental management.** The IAEA has provided support for pollution clean-up options and recovery strategies across various environments, including land, air, marine, and coastal ecosystems. Training and tools have been provided to understand the levels of pollutants in different environments, leading to more informed environmental management decisions.

**Strengthening environmental monitoring capacity.** The IAEA has facilitated training and provided equipment for monitoring environmental radioactivity, harmful algal blooms and ocean acidification. This comprehensive approach has improved Member States' capabilities to assess the impact of pollution and climate change on marine, terrestrial and coastal environments. Capacities for monitoring have been established, allowing for the collection of accurate data on pollutants and their effects. This approach was instrumental for many Member States with a lack of targeted remediation strategies.

**Achievements and results**

Through the implementation of IAEA-supported recommendations and training initiatives, Member States have achieved significant progress in enhancing environmental management and reducing pollution levels across marine, terrestrial and coastal environments.

**Enhanced pollution management.** By incorporating recommendations and training for pollution clean-up options and recovery strategies, Member States have improved their capacity to address pollution sources effectively. The introduction of these strategies, along with enhanced monitoring capabilities, has led to a noticeable reduction in pollution levels across land, air, marine and coastal ecosystems.

**Improved monitoring and understanding.** The establishment of training programs and the provision of equipment for monitoring environmental processes have led to a marked improvement in Member States' capabilities. Enhanced monitoring has facilitated the collection of accurate data on pollutants and their effects, allowing for more informed decision-making and the development of targeted remediation strategies.

**Increased understanding of environmental processes.** Through training initiatives on environmental radioactivity, harmful algal blooms and ocean acidification, Member States have reported an increased understanding of these critical environmental processes. The improved understanding has enabled more effective management of environmental resources and mitigation of environmental threats.

**Impact and perspectives.** Member States have witnessed enhanced pollution management through the implementation of clean-up options and recovery strategies, leading to a noticeable decrease in pollution levels. As Member States continue to build upon these achievements and insights, the TC programme remains adaptable, continuously evolving to meet future demands and address the relevant needs.

1. **ENERGY PLANNING and NUCLEAR POWER**

In the field of nuclear energy planning and introduction, the 21st century posed significant challenges, such as limited capacity for analysing energy supply and demand, inadequate regulatory frameworks for nuclear power and a lack of expertise in energy planning tools. As global energy demands increased, Member States acknowledged the necessity for improved energy planning and strategies to ensure security and environmental protection. Moreover, the introduction of nuclear power projects demanded rigorous planning and regulatory frameworks to ensure safe and efficient operations. These challenges underscored the importance of the TC programme in enhancing energy planning capabilities and facilitating the introduction of nuclear power across Member States.

Through capacity-building initiatives, tailored training, and legislative assistance, the IAEA empowered Member States to establish robust regulatory frameworks and enhance expertise in energy planning. The programme focused on providing essential tools and training for effective nuclear power project management, fostering safe and sustainable energy solutions worldwide.

The impact of the TC programme in the nuclear energy planning and introduction domain enabled Member States to successfully manage nuclear power projects, ensuring adherence to international safety standards and regulatory best practices. Continued collaboration and innovation within the TC programme will remain essential for addressing emerging challenges and maximizing the benefits of nuclear energy in the evolving energy landscape.

1. **Energy planning and introduction of nuclear power.**

***Challenges:*** *Limited capacity for analysing energy supply and demand, inadequate strategies and plans to address future energy needs, the absence of robust regulatory frameworks for introducing nuclear power, insufficient expertise in energy planning tools and environmental monitoring.*

Energy planning is imperative for ensuring sustainable energy supply and meeting the evolving needs of Member States. As the global demand for energy in the 21st century continues to rise, effective planning has become increasingly crucial to address challenges such as supply-demand imbalances, energy security and environmental sustainability. Moreover, the introduction and management of nuclear power projects require meticulous planning and regulatory frameworks to ensure safe and efficient operations. The TC programme has been instrumental to enhance energy planning capabilities and facilitate the introduction of nuclear power in many Member States throughout 21st century.

**IAEA’s multifaceted approach**

Within the framework of the TC programme in the 21st century the IAEA has focused on assistance tailored to concrete needs and demands of Member States introducing nuclear energy. Through capacity-building initiatives, training and legislative assistance, the IAEA has empowered Member States to establish robust regulatory frameworks and enhance expertise in energy planning. Projects designed for these purposes additionally have focused on providing essential tools and training for effective nuclear power project management, fostering safe and sustainable energy solutions worldwide.

**Capacity building and training initiatives.** The training of national energy planning experts in the use of planning tools and methodologies was given a priority in the TC programme projects related to the field of energy planning and introduction of nuclear power. This effort resulted in the establishment of national energy teams proficient in energy modelling and analysis.

**Legislative assistance and regulatory framework development.** One more important direction was related to providing tailored legislative assistance to Member States for the development of comprehensive regulatory frameworks. The support provided through the TC programme aimed to establish robust legal and regulatory frameworks for the safe introduction, operation and lifetime management of nuclear power projects.

**Energy assessment software and environmental monitoring support.** The IAEA focused on delivering energy assessment software tools and related IT equipment, alongside support for enhancing environmental monitoring capacity and technology. These project components aimed to improve data collection, analysis and reporting for informed energy planning and decision-making.

**Training and strategies for nuclear power project management.** The TC programme has offered Member States comprehensive training, strategies, methodologies and systems for effective management of nuclear power projects. Such efforts focused on strengthening expertise in feasibility studies, site characterization and milestone establishment for successful project implementation.

**Achievements and results**

Crucial support has been provided through the TC programme to Member States venturing into nuclear energy introduction. Assistance provided by the IAEA has ensured adherence to international safety standards and has enhanced public confidence in nuclear energy projects. The IAEA has facilitated access to essential infrastructure, technology and expertise, enabling Member States to develop and operate nuclear power plants safely, efficiently and sustainably. The most visible result of this collaboration is the safe and responsible expansion of nuclear energy worldwide.

**Enhanced capacity for energy planning and nuclear power development.** Through capacity-building initiatives, a substantial number of national energy planning experts were trained, national energy teams were established to deliver services in energy modelling and analysis. Furthermore, Member States developed enhanced expertise in conducting feasibility studies, site characterization and establishing milestones for nuclear power projects.

**Establishment of comprehensive regulatory frameworks.** Legislative assistance provided by the IAEA through the TC programme has resulted in the establishment of comprehensive regulatory frameworks for the safe introduction, operation and lifetime management of nuclear power projects in Member States paving their ways to nuclear energy. These frameworks ensure adherence to international safety standards and regulatory best practices, fostering confidence in nuclear energy investments.

**Improved energy planning tools and methodologies.** The delivery of energy assessment software tools and related IT equipment has empowered Member States to enhance their energy planning capabilities. Additionally, support for environmental monitoring capacity and technology facilitated better data collection and analysis, enabling evidence-based decision-making in energy planning and policy development.

**Effective management of nuclear power projects.** Member States have successfully managed nuclear power projects with the expertise gained through training, strategies and methodologies provided by the TC programme. Feasibility studies, site characterization and milestone establishment became integral components of policy and decision-making processes, ensuring the safe and efficient implementation of nuclear energy projects worldwide.

**Impact and perspectives.** The TC programme has empowered Member States to assess the viability of nuclear energy projects, establish regulatory frameworks and make informed decisions, thereby facilitating the safe and sustainable expansion of nuclear power. As nations worldwide face increasing energy demands and seek to transition towards cleaner and more sustainable energy sources, nuclear power emerges as a viable option. Many Member States are considering or actively pursuing nuclear energy projects to meet their growing energy needs while reducing greenhouse gas emissions. In this context, the TC programme will continue to play a crucial role by providing essential training, expertise, and support in energy planning and nuclear project management.

1. **Nuclear power reactors.**

***Challenges:*** *Limited expertise in environmental qualification programs, uncertainties surrounding long-term operation, regulatory incompliance, underdeveloped accident prevention strategies, weak safety measures, public concerns related to nuclear energy.*

The introduction, operation, and management of nuclear power reactors require thorough planning, stringent safety measures and continual oversight to ensure both operational efficiency and environmental protection. In the 21st century, the IAEA through the TC programme has provided guidance and support to Member States at every stage of the process, from initial planning and licensing to operational safety protocols and decommissioning strategies. The framework for knowledge sharing, created within the TC programme, has facilitated the responsible utilization of nuclear energy resources, ensuring that safety standards are upheld and environmental concerns are addressed worldwide.

**IAEA’s multifaceted approach**

The TC programme has proven to be highly effective and efficient in addressing the diverse needs and challenges faced by Member States in the field of nuclear energy in the 21st century. Strategic focus has been placed on critical aspects of nuclear energy development such as environmental qualification programs, sustainable operation of NPPs, plant safety, accident prevention and the management of introducing new NPPs. Furthermore, by prioritizing collaboration, capacity-building and institutional strengthening, the program has encouraged Member States to work together, enhancing sustainable progress and innovation in nuclear energy.

**Environmental qualification (EQ) programs.** The TC programme has prioritized comprehensive training and infrastructure support for EQ programs, aimed at enhancing Member States' capabilities in conducting EQ tests and meeting national regulatory standards. These efforts have been essential for ensuring the safety, reliability, and compliance of nuclear facilities as well as fostering public confidence and international cooperation in the nuclear energy sector.

**Guidance for sustainable operation of NPPs.** Through the TC programme the IAEA has provided tailored recommendations on the long-term operation of nuclear power plants, focusing on enhancing operational lifetimes while ensuring safety, regulatory compliance, and sustainability. Relevant guidance and support provided to nuclear operators through the TC programme in the 21st century aimed at maintaining the integrity and viability of nuclear power generation in interested Member States.

**Plant safety and accident prevention capacity and plans.** Efforts have been directed towards the development and implementation of draft plans for accident prevention, integrating improved safety measures and accident prevention strategies into NPP operations.

**Guidance on management of introduction of new NPPs.** The TC programme has provided recommendations to all interested Member States to address regulatory, technical and institutional challenges in introducing new NPPs. These efforts have facilitated their construction and operation, while promoting compliance, technical expertise, institutional capacity building and the development of nuclear energy.

**Specialized training and knowledge-sharing initiatives on SMRs.** Specialized training and knowledge-sharing initiatives were undertaken to enhance Member States' understanding of SMRs and facilitate the integration of new reactor technologies into national energy plans. Such collaboration has aimed at effective incorporation of SMRs into Member States energy systems, optimizing their contribution to energy security and sustainability.

**Achievements and results**

The TC programme has strengthened Member States' capabilities in decision-making, safety and operational efficiency within the nuclear power sector. IAEA guidance has been integrated into Member States practices enhancing their ability to navigate challenges, ensuring safety compliance and expanding their nuclear energy capacity sustainably.

**Integration of IAEA recommendations into decision-making processes.** Decisions and plans based on the recommendations and support provided by the IAEA through the TC programme have been widely implemented by Member States. This integration has led to more informed decision-making processes and enhanced safety measures in nuclear power operations, contributing to the overall reliability and resilience of nuclear energy infrastructure.

**Enhanced capacity and planning in safety and accident prevention.** The capacity-building initiatives facilitated by the IAEA have been effectively integrated into safety and accident prevention decision-making processes. Member States have demonstrated improved capabilities in identifying potential hazards, implementing proactive safety measures and developing comprehensive accident prevention strategies. This has led to minimizing risks and ensuring the continued safe operation of nuclear power facilities in Member States.

**Implementation of recommendations for new nuclear power plant introduction.** Relevant institutions have successfully implemented recommendations provided by the IAEA for the introduction of new nuclear power plants. This proactive approach has streamlined the process of NPP construction and operation, ensuring adherence to international safety standards and regulatory best practices. As a result, Member States have been able to expand their clean energy production capacity while maintaining high levels of safety and operational efficiency.

**Integration of improved institutional capacity into planning and decision-making.** The enhanced institutional capacity, developed through training and technical assistance provided by the IAEA, has been integrated into planning and decision-making processes. Member States now possess the expertise and resources necessary to develop comprehensive strategies for nuclear energy development, ensuring the efficient utilization of resources and the effective implementation of regulatory frameworks.

**Increased knowledge and capacities in SMR technology.** The TC programme's focus on training and knowledge-sharing initiatives has resulted in a notable increase in knowledge and capacities related to SMR technology among Member States. This enhanced understanding has empowered institutions to explore the potential of SMRs as viable options for clean energy production, contributing to the diversification of energy sources and the promotion of sustainable development goals.

**Improved construction and management of nuclear power plants.** The support provided by the IAEA through the TC programme has significantly improved the construction and management of nuclear power plants. Member States have demonstrated enhanced capabilities in ensuring the safe introduction, operation and lifetime management of nuclear power facilities.

**Impact and perspectives.** With support provided by the IAEA through the TC programme, Member States have witnessed tangible improvements in the safety, reliability and sustainability of their nuclear power infrastructure. International cooperation and knowledge-sharing in addressing complex challenges in the nuclear energy sector have become crucial for this purpose. These results highlight the importance of continued investment in capacity-building and technology transfer where the TC programme lays the groundwork for a more resilient and sustainable nuclear energy landscape.

1. **Nuclear fuel cycle.**

***Challenges:*** *Limited availability of dependable reference products, shortage of analytical expertise and quality assurance measures, inadequate waste management practices, optimization of resource utilization, nuclear safety and security concerns.*

In the 21st century, the management of the nuclear fuel cycle has become increasingly crucial for ensuring the safe and sustainable utilization of nuclear energy resources. As Member States prioritize initiatives aimed at enhancing safety, security, and sustainability throughout the nuclear fuel cycle, various advancements have been made in reactor technology, waste management strategies, regulatory frameworks, and international cooperation efforts. The TC programme has provided an effective framework for relevant capacity building and knowledge-sharing. Member States continue to leverage improved knowledge and capacity in their nuclear fuel cycles.

**IAEA’s multifaceted approach**

Member States have increasingly prioritized initiatives aimed at enhancing safety, security and sustainability throughout the nuclear fuel cycle. Such efforts have included advancements in reactor technology to improve efficiency and safety, development of innovative waste management strategies to address long-term disposal challenges as well as implementation of rigorous regulatory frameworks to ensure compliance and accountability, as well as promotion of international cooperation to share best practices and address common challenges collectively.

**Enhancing technical capacity in hot cell operations.** The TC programme has prioritized comprehensive training initiatives aimed at enhancing Member States' technical capacity in the use of hot cells for nuclear fuel cycle activities. Through specialized training sessions and knowledge-sharing workshops, professionals have been equipped with essential skills and expertise to operate hot cells effectively, ensuring the safe handling and processing of radioactive materials.

**Fostering high-level nuclear waste disposal.** Recognizing the importance of safe and sustainable disposal of high-level nuclear waste, the TC programme has focused on providing training and essential equipment to Member States for effective waste management practices. Training sessions have covered various aspects of waste disposal, including site selection, engineering design, and regulatory compliance, while the provision of equipment has enabled Member States to establish and enhance their waste disposal facilities.

**Optimizing resource utilization in nuclear fuel cycle operations.** The TC programme has facilitated training initiatives on the identification and recovery of uranium and rare earth elements from nuclear fuel cycle materials. By equipping professionals with advanced techniques and methodologies, Member States have been able to optimize resource utilization, minimize waste generation, and enhance the sustainability of their nuclear fuel cycle operations.

**Achievements and results**

The TC programme has significantly contributed to enhancing nuclear fuel cycle management across Member States. Through training and capacity building initiatives, the programme has improved safety and efficiency in handling radioactive materials. Laboratories now have better infrastructure for waste disposal and professionals in participating Member States are equipped to optimize resource extraction and fuel management. These efforts have led to improved operational efficiency and safety standards, aligning with the general requests of Member States.

**Training and technical capacity in hot cell utilization.** The TC programme's emphasis on training and technical capacity building in the use of hot cells has resulted in improved operational efficiency and safety in nuclear fuel cycle activities. Professionals trained in hot cell utilization have demonstrated enhanced skills in handling radioactive materials, conducting fuel cycle processes, and ensuring compliance with safety standards, contributing to the overall reliability and sustainability of nuclear fuel cycle operations.

**Laboratory capacity and performance assessment of high-level nuclear waste (HLW) disposal.** Member States have made significant progress in the development and enhancement of laboratory capacity for the performance assessment of high-level nuclear waste disposal, thanks to support from the TC programme. Improved laboratory infrastructure and analytical capabilities have enabled more accurate characterization and monitoring of radioactive waste, facilitating effective waste management and disposal strategies.

**Capacities for the identification and recovery of uranium and rare earth elements.** Training initiatives on the identification and recovery of uranium and rare earth elements have led to enhanced resource utilization and sustainability in the nuclear fuel cycle. Professionals equipped with advanced knowledge and skills have optimized extraction processes, minimized environmental impact, and promoted responsible mining practices, contributing to the efficient and environmentally sound management of nuclear resources.

**Improved post-irradiation test services.** The TC programme's support in improving post-irradiation test services has enabled Member States to conduct more comprehensive and efficient testing of nuclear fuel materials and components. Enhanced testing capabilities have facilitated the development of advanced nuclear fuel technologies, leading to improved fuel performance, safety, and reliability in nuclear power plants.

**Experimental results and knowledge advancement.** Member States have leveraged improved knowledge and capacity in the nuclear fuel cycle to produce experimental results that contribute to ongoing research and development efforts in nuclear energy technology. Enhanced experimental capabilities have enabled the validation of theoretical models, the optimization of fuel cycle processes, and the exploration of innovative fuel designs, fostering innovation and advancement in the nuclear energy sector.

**Resource information generation and optimization of extraction processes.** The TC programme's support in capacity building for resource information generation and optimization of extraction processes has empowered Member States to make informed decisions regarding nuclear resource utilization and management. Improved resource mapping techniques and extraction processes have enhanced resource efficiency, minimized environmental impact, and promoted sustainable development in the nuclear fuel cycle.

**Improved nuclear fuel management.** Through the TC programme, Member States have achieved significant improvements in nuclear fuel management practices, including fuel fabrication, utilization, and disposition. Enhanced fuel management capabilities have led to increased fuel efficiency, reduced waste generation, and improved safety and security in nuclear power operations, contributing to the overall sustainability and resilience of the nuclear fuel cycle.

**Impact and perspectives.** Participating in the TC programme, Member States have significantly improved operational efficiency and resource utilization in their nuclear fuel cycles. Actions such as ongoing training programs, collaborative research efforts and technological advancements will be essential to address emerging challenges and maximize the benefits of nuclear energy in the mid-term perspective.