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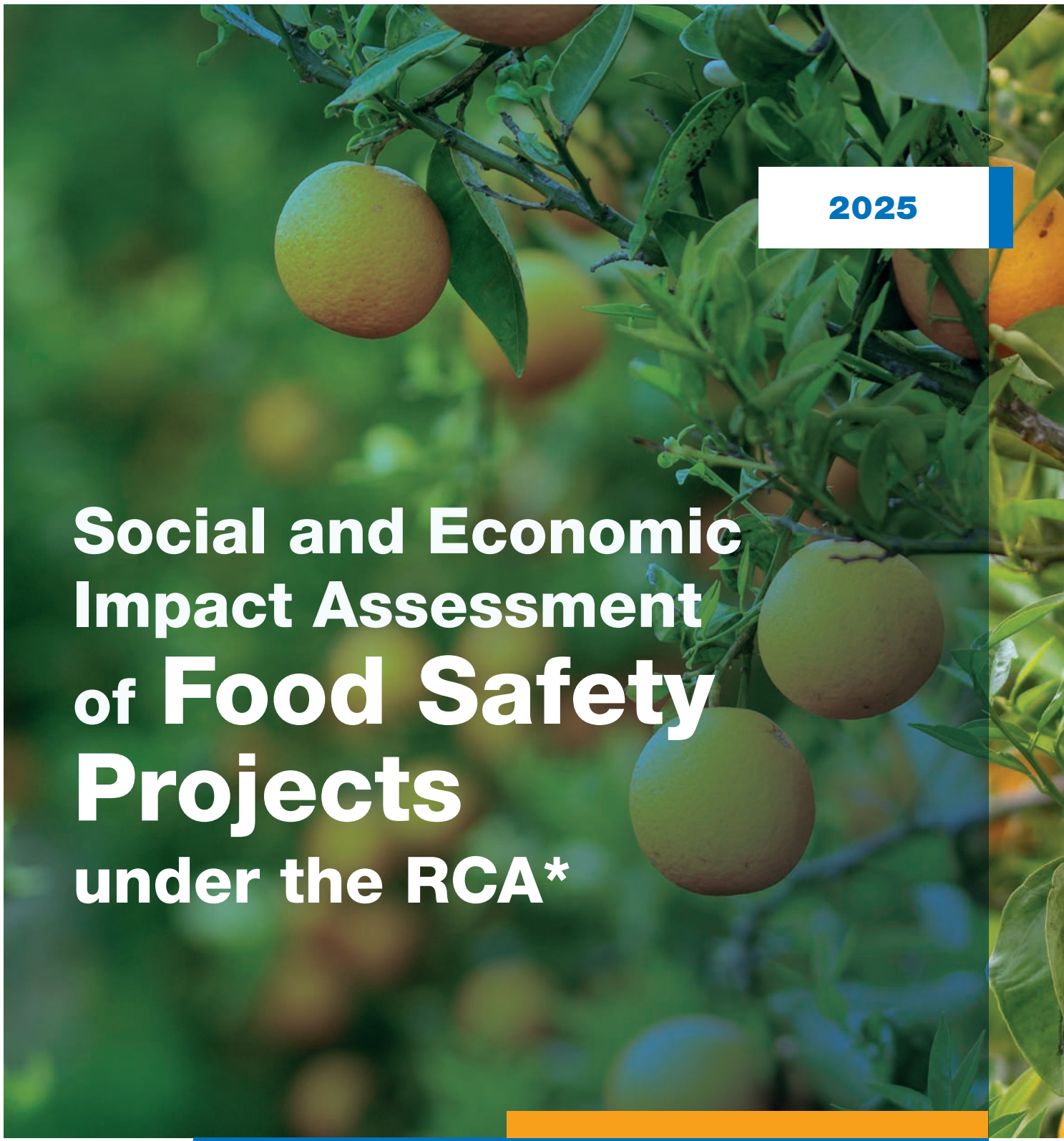

2025

Social and Economic Impact Assessment of Food Safety Projects under the RCA*

RCA

*REGIONAL COOPERATIVE AGREEMENT TECHNICAL COOPERATION PROGRAMME IN ASIA AND THE PACIFIC

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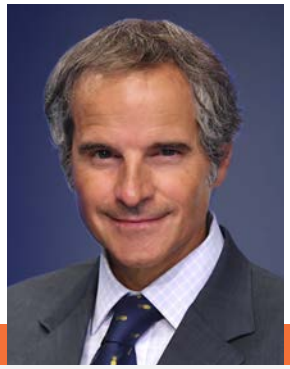

FOREWORD

RAFAEL MARIANO GROSSI

Director General, International Atomic Energy Agency

Making a positive impact through nuclear science and technology

The partnerships between the IAEA and its Member States play an important role in driving social and economic progress. The Asia-Pacific region has a rich diversity and abundant social, economic, technological and intellectual capital to draw from to accelerate sustainable development and drive long term progress. For more than five decades, the IAEA has collaborated closely with and supported RCA State Parties through this regional cooperation platform to promote the peaceful application of nuclear science and technology in addressing critical societal needs. Nuclear applications have contributed significantly to advancements in healthcare, food security, agriculture, water and environmental management, industrial development, and safety and security. These contributions have strengthened national and regional capacities, improved livelihoods, and stimulated economic growth across the region.

This series of reports evaluates the social and economic impact of RCA projects in application of nuclear techniques in air quality monitoring, food safety, nuclear medicine, and isotope hydrology, highlighting the tangible benefits and lasting outcomes of nuclear technology in these key development areas.

The IAEA is increasing its impact through the IAEA's flagship initiatives I have launched over the past five years. These include: Rays of Hope, which is helping close the gap in cancer care; Atoms4Food, which is boosting food security and safety and agricultural progress together with the Food and Agriculture Organization of the United Nations (FAO); NUTEC Plastics, which is helping to reduce microplastic pollution in the ocean and improve plastic recycling; Zoonotic Disease Integrated Action (ZODIAC), which is increasing countries' ability to spot and stop the next zoonotic disease outbreak; and Atoms4NetZero, which supports energy transitions, including through the use of nuclear energy. The continued commitment of RCA Member States to these strategic initiatives is important in ensuring long term sustainability and ongoing beneficial impact to lives and livelihoods across the region.

Rafael Mariano Grossi
Director General, International Atomic Energy Agency

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EXECUTIVE SUMMARY

The treaty-level Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA) was established in 1972 under the auspice of the IAEA. The RCA was established with the aim of strengthening and promoting cooperation among RCA State Parties (SPs). This report assesses the social and economic impacts of food safety projects under the RCA (referred to as RCA FS projects or the RCA FS programme), focusing on value added over and above the primary research undertaken independently by individual countries.

Food safety is of paramount importance to protect the health of the consumer and to help ensure food security. The RCA FS programme focuses on food irradiation and nuclear techniques for food origin authentication.[1] It contributes directly to the achievement of the United Nations' Sustainable Development Goals (SDGs) 1, 2 and 12 — no poverty, zero hunger and responsible production — because food safety and quality form integral parts of these SDGs. In many countries, people's health and livelihoods depend on food production, and food exports are often a major contributor to the economy. Trade is globalized, so a food safety crisis or incident in one country could eventually affect consumers in many other countries and regions. To address these transboundary challenges, joint efforts worldwide are needed to enhance food safety and quality.

The IAEA, in partnership with the Food and Agriculture Organization of the United Nations (FAO), supports SPs in developing and applying nuclear techniques (specifically food irradiation and food origin authentication) to improve their food safety and control systems. Health, environmental and economic benefits are realized through the RCA FS programmes that enable SPs to receive training and support to establish infrastructure and research and development (R&D) capacity. These lead to raised awareness and understanding of the value of these techniques, enhanced and effective application and harmonized standards, guidelines and protocols.

This impact assessment was designed and undertaken by a team of external experts in consultation with the IAEA and RCA SPs. It involved gathering evidence through an online survey that was completed by 19 of the 22 participating SPs, analyzing IAEA administrative data, gathering information from food safety experts at the IAEA and SPs, analyzing narrative success case examples of food safety programmes from five SPs and examining the economic analysis of costs and benefits of food safety activities under the RCA.

[1] Food safety is a very broad topic. The RCA FS focuses on food irradiation and nuclear techniques for food origin authentication, so when this report uses the term 'food safety' for brevity it is referring to both of these techniques. Where one or the other technique is being specifically talked about this will be noted in the report.

The impact assessment found that the RCA supported SPs to:

- Enhance local expertise in participating SPs through training between **93** and **259** personnel in each aspect of food irradiation and between **10** and **63** personnel in each aspect of food origin authentication.
- Improve national R&D for food irradiation and food origin authentication by generating approximately **490** research publications.
- Establish infrastructure for food analysis, irradiation and authentication by enabling the creation of **128** facilities dedicated to these techniques.
- Raise awareness and understanding of governments and businesses about the value of food irradiation and food origin authentication in **18** out of 19 countries.
- Enable some development and adoption of harmonized standards, guidelines and protocols for food irradiation and food origin authentication in **12** out of 19 countries.
- Effectively support enhanced and effective application of irradiation (**12** countries) and food origin authentication technologies (**11** countries) for R&D and commercial purposes.
- Realize economic benefits by reducing the costs of foodborne illness and food waste, plus other potential benefits that could not be quantified at this stage.
- Support health and environmental benefits through reduced morbidity and mortality caused by foodborne illness (**13** countries); transparency in the food supply chain (**12** countries) and reduced chemical use post-harvest (**12** countries).

Pre-defined performance criteria were agreed upon with IAEA and SP experts to provide an evaluative framework for the impact assessment (Tables VII–1 – VII–7, Annex VII). Based on the evidence provided by the IAEA and SPs, the RCA's impacts meet standards for **excellent performance** across one impact domain (established infrastructure and improved national R&D). Further, it achieved **good performance** across six impact domains (national trained personnel; raised awareness and understanding; harmonized standards, guidelines and protocols; enhanced and effective application; economic benefits; and health and environmental benefits).

1.

Introduction

The IAEA is the world's central intergovernmental forum for scientific and technical cooperation in the nuclear field. Established in 1957 and headquartered in Vienna, Austria, the IAEA works for the safe, secure and peaceful uses of nuclear science and technology, contributing to international peace and security and the United Nations Sustainable Development Goals (SDGs). The IAEA works in close partnership with Member States, United Nations agencies, research organizations and civil society to maximize the contribution of nuclear science and technology to achieving development priorities ('Atoms for Peace and Development').

The Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA), under the auspice of the IAEA, was established in 1972 and has enjoyed the benefit of the IAEA Technical Cooperation (TC) programme since. With the RCA celebrating its 50th anniversary in 2022, it is timely to assess the social and economic impacts of the RCA supported under the IAEA TC programme.

At the 48th RCA General Conference Meeting in Vienna, Austria, on 13 September 2019, the RCA endorsed the initiative to conduct social and economic impact assessments. To this end, the TC Division for Asia-Pacific (TCAP) and TC Division of Programme Support and Coordination (TCPC) jointly proposed undertaking case studies. Three social and economic impact assessments were finalized in the fields of human health (radiotherapy, 2022), agriculture (mutation breeding, 2020), and industry (non-destructive testing, 2022). In 2024, another social and economic impact assessment was finalized in the field of air quality monitoring. This fifth report presents the social and economic impact assessment findings of the food safety programmes under the RCA (referred to in this report as RCA FS programmes). Future case studies are planned for nuclear medicine and hydrology.

1.1. Food safety[1]

The IAEA, in partnership with the Food and Agriculture Organization of the United Nations (FAO), supports State Parties (SPs) in the development and application of nuclear techniques to improve their food safety and control systems. Food safety is of paramount importance to protect the health of the consumer and to help ensure food security. The RCA FS programme contributes directly to the achievement of the United Nations' Sustainable Development Goals (SDGs) 1, 2 and 12 – no poverty, zero hunger and responsible production – because food safety and quality form integral parts of these SDGs.

In many countries, people's health and livelihoods depend on food production, and food exports are often a major contributor to the economy. Trade is globalized, so a food safety crisis or incident in one country could eventually affect consumers in many other countries and regions. To address these transboundary challenges, joint efforts worldwide are needed to enhance food safety and quality. The two focus areas of the RCA FS programmes are food irradiation and nuclear techniques for food origin authentication:

- Food irradiation controls food spoilage and foodborne pathogens or insect pests without significantly affecting the taste, look or smell of the foods. An estimated 600 million people fall ill after eating contaminated food, and 420 000 die every year. Further, foodborne diseases can harm national economies and trade [2]. Food irradiation is a regulated technology that employs energy in the form of gamma radiation, X rays or high energy electron beams to suppress spoilage and eliminate foodborne pathogens or post-harvest pests, reducing the risk of foodborne illness as well as food waste and spoilage.
- Food origin authentication protects against food fraud and supports transparency in food supply chains. It determines the authenticity of a food product, including its origin, species, variety and production methods. Isotopic and related techniques play a unique role in food safety, quality and control systems. They can help identify and combat fraudulent, adulterant and illegal additives in food and feed; determine food origin; verify product authenticity; and test and quantify various harmful residues or contaminants such as pesticides, veterinary drugs, mycotoxins or heavy metals.

The IAEA and FAO support SPs through applied research, training and technical guidance on the application of nuclear, isotopic and irradiation technologies to strengthen national practices and capabilities in food irradiation and food origin authentication. This facilitates reliable, routine control programmes that, besides safeguarding consumers, enhance food export opportunities.

[1] This summary includes verbatim or slightly modified passages from the following IAEA Factsheet called Monitoring and Sustaining Food Safety and Quality with Nuclear Techniques, which provides general information on Food Safety and was provided to the evaluation team by the IAEA [1].

1.2. Social and economic impact assessment methods

The social and economic impact assessment methodology was developed specifically for conducting impact assessments for case studies of TC projects under the RCA. The methodology follows the Value for Investment approach [3–5] and the Kinnect Group approach to evaluation rubrics [6, 7], combining evidence from quantitative, qualitative and economic analysis, through the lens of an agreed performance framework, to evaluate the impact of food safety programmes under the RCA.

Social and economic impacts of the RCA food safety programmes are diverse and include contributing to a chain of impacts (see theory of change, Annex VIII) that incorporates:

- National personnel trained in food irradiation and food origin authentication, *and*
- Developing technical infrastructure, *and*
- Improved national research and development capacity, *leading to*
- Established infrastructure and improved national research and development (R&D), *and*
- Raised awareness and understanding about the value of food irradiation and food origin authentication, *and*
- Enhanced and effective application of irradiation and nuclear technologies, *and*
- Harmonized standards, guidelines and protocols for food irradiation and food origin authentication, *and*
- Health and environmental benefits including reduced use of chemicals, reduced food waste, reduced morbidity and mortality from foodborne illness, reduced potential of biosecurity threats, overcoming trade barriers and increased transparency in the agricultural-food supply chain.

The food safety case study used a mix of methods to assess these different types of impacts. These methods included:

- An online questionnaire deployed to all countries in the RCA and completed by 19 of the 22 SPs;
- Analysis of administrative data on food safety activities and costs, provided by the IAEA;
- Gathering of additional information from food safety experts at the IAEA and SPs;
- Narrative case examples, written from details provided by five countries on a selection of ‘success cases’ of food safety programmes;
- Economic analysis of costs and benefits of food safety programmes under the RCA.

Evaluation rubrics were developed to combine quantitative, qualitative and economic analyses. These rubrics, comprising a matrix of agreed criteria (aspects of performance) and standards (levels of performance), provided a transparent and robust framework for rating the social and economic impact of food safety under the RCA from the mix of evidence. Refer to Annex VIII for full details of the methodology.

2.

Social and economic impacts

The RCA has successfully supported participating SPs in the Asia and Pacific region to undertake considerable work to increase food safety in the areas of food irradiation and nuclear techniques for food origin authentication. This impact assessment focuses on the last two decades, since 2000, and focuses on the value added by the RCA, beyond the growth that could have occurred within the individual countries if the RCA did not exist.

The RCA contributed to increased training and infrastructure support for food irradiation and food origin authentication, resulting in greater awareness of the value of these technologies and a greater capacity to consistently use them to benefit people's health and realize economic benefits.

Of the 22 countries that are part of the RCA, 19 responded to the survey. Eighteen SPs replied to the food irradiation survey, and 14 replied to the food origin authentication survey. The following analysis presents the outcomes from the 19 countries that participated in the survey. However, it is essential to acknowledge that three of these countries — Cambodia, Fiji and Nepal — while being signatories to the RCA, have not been extensively engaged in the activities of the RCA FS programme. Furthermore, three of them are considered newcomers to the RCA. Consequently, the programme's impact on these countries' accomplishments across all evaluation metrics is limited. It is recommended that the findings in this report be interpreted with this context in mind.

2.1. National personnel trained in all aspects of food irradiation and/or use of nuclear technologies for origin authentication

The RCA programme has successfully enhanced local expertise in participating SPs in food irradiation and food origin authentication. Personnel were trained in food irradiation in 17 of the 19 SPs that replied to the survey. Three SPs (China, Myanmar and Thailand) have personnel trained in all aspects of food irradiation. **Between 93 and 259 personnel were trained** in each aspect of food irradiation, and **between 10 and 63 personnel were trained** in each aspect of food origin authentication.

For food irradiation, the most common techniques personnel were trained in were sanitary and phytosanitary treatment (259 trained personnel) and quality assurance and quality control systems (235 trained personnel). Table 1 shows how many personnel were trained in each aspect of food irradiation.

Table 1. Total number of nationally trained personnel in each aspect of food irradiation.

Area	Personnel trained
Sanitary and phytosanitary treatment	259
Quality assurance and quality control systems	235
Electron beam and X ray technology	187
Commercial applications	176
Public information on the use of irradiation	149
Other topics	135
Quarantine security in trade	108
Microbiological safety	93

For food origin authentication techniques, the most common training area was the fundamentals of using nuclear techniques for food authentication (63 personnel). Two countries (Japan and New Zealand) have personnel trained in all aspects of food origin authentication. Table 2 identifies how many personnel were trained across all participating SPs in each aspect.

Table 2. Total number of nationally trained personnel in food origin authentication.

Area	Personnel trained
Fundamentals of using nuclear techniques for food authentication	63
Data analysis for food authentication	27
Other topics	10

For example, in Myanmar, approximately ten members participated in a series of hands-on regional training sessions, workshops and expert missions,[2] significantly enhancing their expertise in food irradiation. National experts were also trained in a range of critical topics, including electron beam and X ray technology, microbiological safety, sanitary and phytosanitary treatments, quality assurance and control, and the commercial applications and public awareness of food irradiation. This development in human capacity has enabled Myanmar to produce over 30 high quality research outputs and publications on the subject, focusing on the use of irradiation for agricultural products such as rice, beans and pulses—key export commodities for the country.

In Viet Nam, the RCA FS programme provided specialized workshops and hands-on training sessions, enhancing the expertise of Vietnamese scientists and technicians in the application of nuclear and related techniques for food origin authentication. This included comprehensive instruction in data analysis as well as the foundational principles of advanced techniques such as elemental analysis-isotope ratio mass spectrometry (EA-IRMS), inductively coupled plasma mass spectrometry (ICP-MS), and Fourier transform infrared spectroscopy (FTIR). The training opportunities offered through the RCA FS programme enabled Vietnamese researchers to acquire proficiency in stable isotope techniques, ensuring that food authentication could be conducted with a high degree of precision while simultaneously contributing to the development of robust and reliable food safety systems within the country.

In Japan, the RCA FS programme provided national scientists with the opportunity to participate in a variety of training courses, greatly contributing to the improvement of their technical capabilities in the application of nuclear techniques for food origin authentication. The programme also facilitated international collaboration among research institutes, fostering an environment where countries facing similar challenges could share their technological advances and collaboratively develop potential solutions. This international cooperation facilitated the collection and analysis of authentic rice samples from fourteen countries, and honey samples from five countries, contributing to the creation of a thorough sample database for the Asia and the Pacific region.

[2] Some of the most significant projects through which capacity development was achieved include RAS5061, RAS5062, RAS5071, RAS5078, RAS5081 and RAS5087.

2.2. Established infrastructure and improved national research and development for food irradiation and food origin authentication

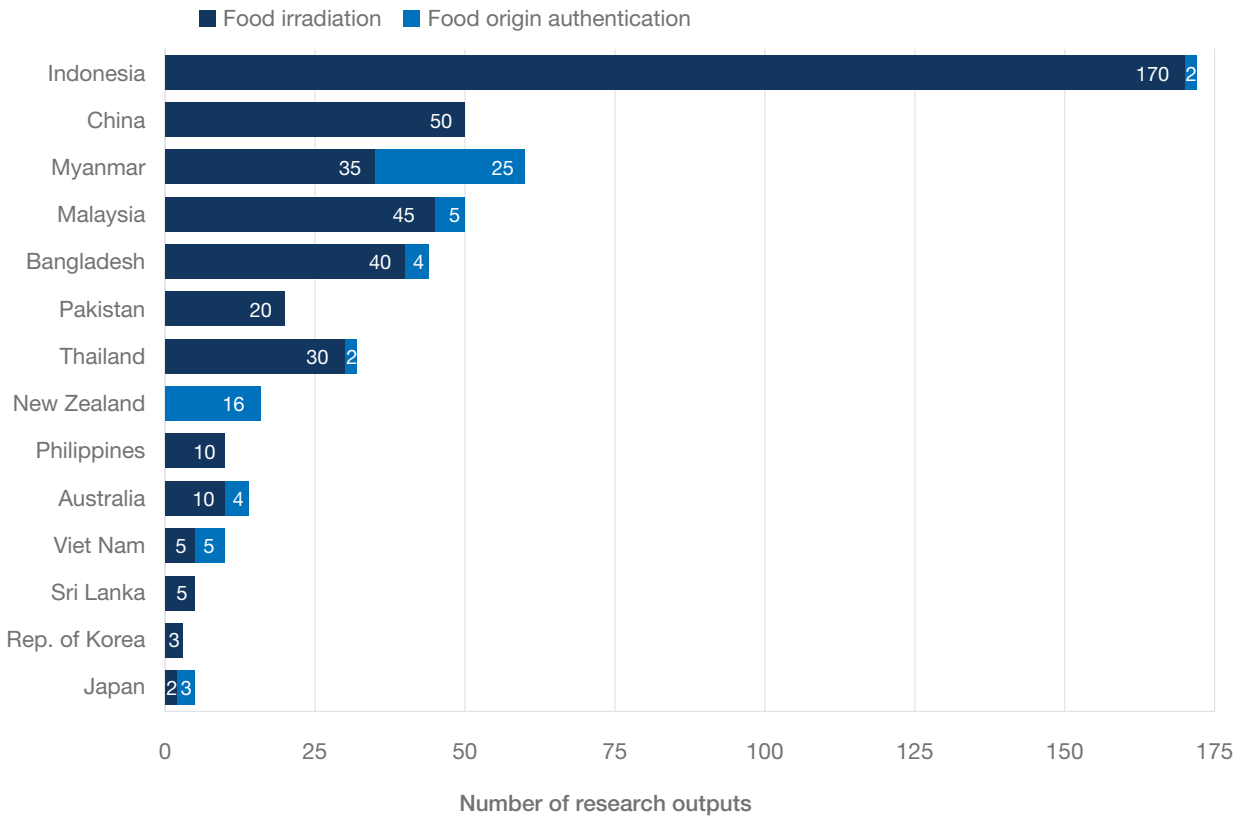
Participation in the RCA has substantially impacted the establishment of infrastructure and improved national R&D for food irradiation and food origin authentication. Participation has bolstered national R&D capabilities, enabling countries to conduct advanced research in food safety and quality. Furthermore, the RCA programme has supported the development of essential infrastructure, particularly laboratory facilities for food analysis, irradiation processes and food origin authentication. The facilities are foundational to modern food safety and quality control systems.

2.2.1. Improved national research and development for food irradiation and food origin authentication

Between 2000 and 2023, the RCA FS programme has contributed to approximately **490** research publications (Fig. 1). Approximately 85% of these publications are in the area of food irradiation, reflecting the programme's emphasis on using food irradiation to improve food safety, extend shelf time and meet international quality standards. Research in this area includes studies on the effects of irradiation on various food products, optimization of irradiation protocols, safety assessments and investigations into consumer acceptance and regulatory compliance. These publications contribute to a growing body of evidence supporting food irradiation as a viable method for enhancing food safety and preserving food quality.

When asked to identify the extent of the contribution of the RCA, most countries identified that participation in the RCA has contributed to research outputs for both food irradiation and food origin authentication to a significant extent.

FIG. 1. Research outputs and publications produced as part of being part of the RCA FS programme.

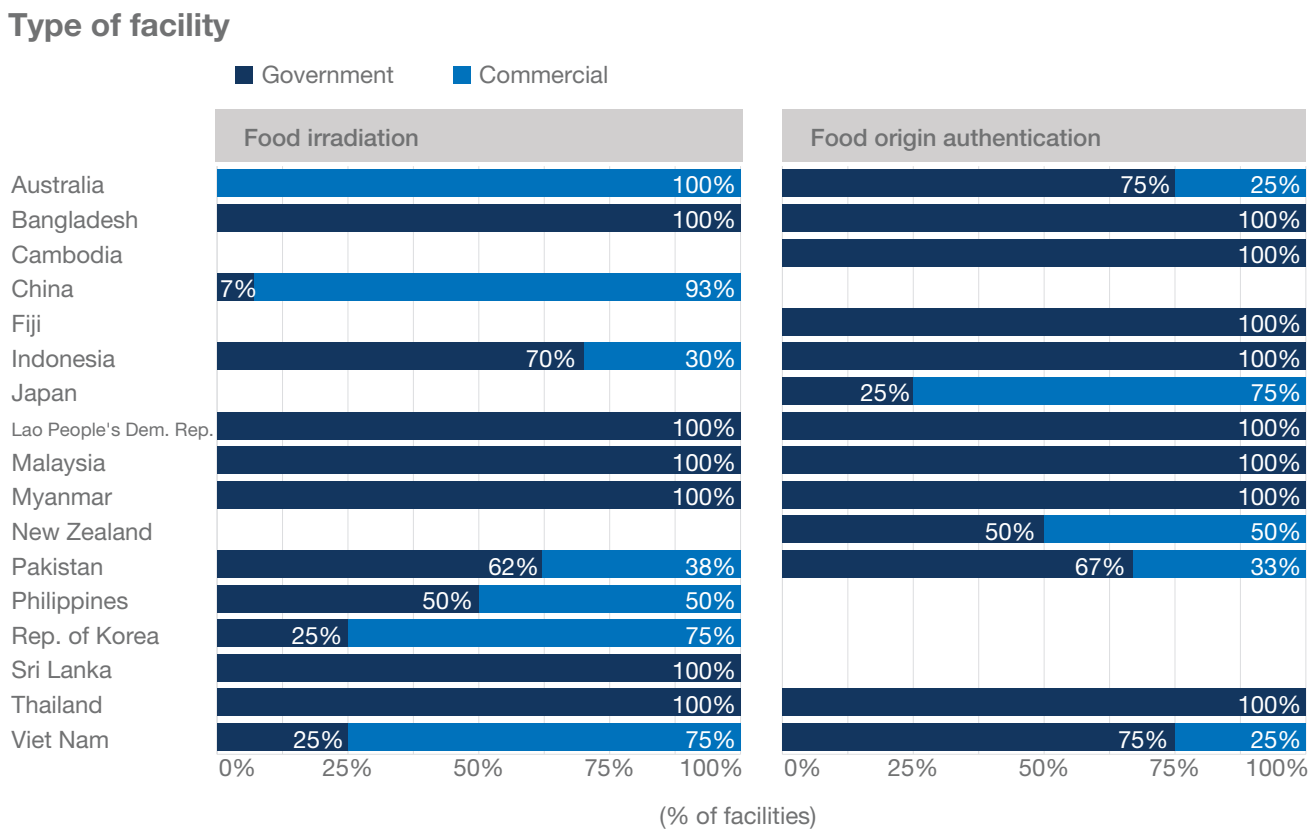


2.2.2. Establishing infrastructure for food analysis, irradiation and authentication

Participation in the RCA FS enabled the establishment of approximately **410** facilities dedicated to food analysis, food irradiation and food origin authentication. Of these, 19% are owned and operated by government entities, while 81% are commercial, privately owned facilities. The majority (about 91%) focus on food irradiation.

Figure 2 illustrates the proportion of food irradiation and food origin authentication facilities owned by the Government versus those owned by the private sector in each country. The extent to which SPs believed participation in the RCA had contributed to the development of government facilities varied. Just under half of the survey respondents (5 of 12) identified a significant contribution of participation in the RCA to the development of government facilities for food irradiation, whereas over half of survey respondents (8 of 14) believed that participation in the RCA contributed significantly to the development of government facilities for food origin authentication. These findings highlight the varying structures of facility ownership across different countries and the subsequent degree of impact that participation in the RCA can have.

FIG. 2. Proportion of facilities owned by governments and private sectors.



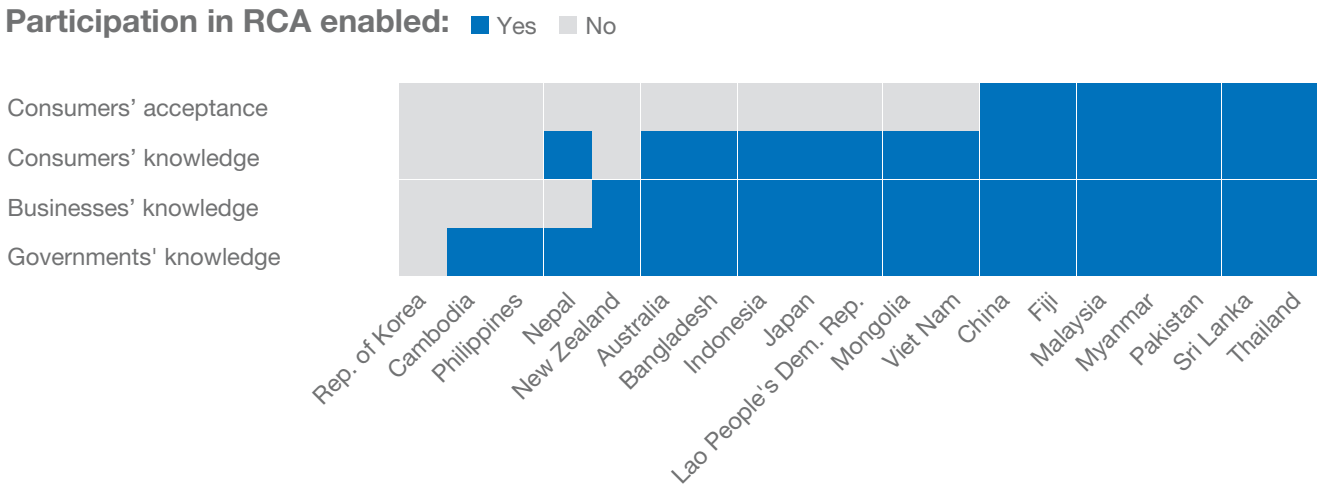
In Malaysia, participation in the RCA FS programme significantly contributed to the establishment and development of Malaysia's two government facilities for food origin authentication, which include stable isotope and elemental analysis capabilities. In particular, the programme provided essential guidance on the technical specifications required to develop these facilities and recommendations on the equipment needed to ensure the facilities had advanced analytical tools suitable for food authentication. The programme also offered advice on designing the laboratory environment and optimizing the arrangement of equipment to meet international standards.

Viet Nam's participation in the RCA FS programme significantly advanced high quality national research on food origin authentication, thereby contributing to the global body of knowledge on the subject and highlighting Viet Nam's progress in this field. A prime example of this contribution is the research initiative on honey adulteration, which utilizes stable isotope techniques, such as $\delta^{13}C$ analysis, to detect C4 sugar adulteration in honey. The results of this research have been disseminated internationally, elevating Viet Nam's reputation in the domain of food safety research.

2.3. Raised awareness and understanding among governments, businesses and the public about the value of food irradiation and food origin authentication

This analysis identified that participation in the RCA FS programme has raised awareness and understanding of the value of food irradiation and food origin authentication (Fig. 3). This impact assessment identified that in **18 out of 19 SPs**, there is marked improvement in governments' and businesses' knowledge about the value of food irradiation and/or food origin authentication. Findings about the influence of the RCA FS programme on consumer knowledge and acceptance are more mixed, indicating there are still gains to be made. While **seven** SPs identified improvement in consumers' acceptance of food irradiation and/or food authentication, 12 SPs identified that only consumer awareness had improved, and four SPs identified no improvement in consumer awareness or acceptance.

FIG. 3. RCA FS programme's contribution to raise awareness and understanding about the value of food irradiation and food origin authentication.



For example, Thailand utilizes irradiation technology across three government facilities for various food products and purposes. These include, among others, the elimination of microorganisms in herbs, spices and frozen seafood to enhance food safety for both domestic consumption and export, as well as meeting phytosanitary requirements for the export of fresh fruits to countries such as Australia, New Zealand and the United States of America. A notable success story is the use of irradiation for naem, a fermented pork product. In this product, irradiation is employed to eliminate potential microorganisms and extend shelf life by delaying the development of acidity. Naem has become the most successful irradiated food product in the country. It is widely available in popular convenience stores, reflecting the high level of consumer trust in the product.

In Viet Nam, one of the primary advantages of the adoption of food authentication technology has been the enhancement of consumer confidence in the products available in the national market. Vietnamese consumers can now rely on the assurance that the food they purchase, whether domestic or imported, meets food safety standards. The use of stable isotope techniques in verifying the origin of products such as honey, apples or pork has provided consumers with the confidence that these products are free from adulteration and mislabelling, fostering a sense of trust in the integrity of the food supply.

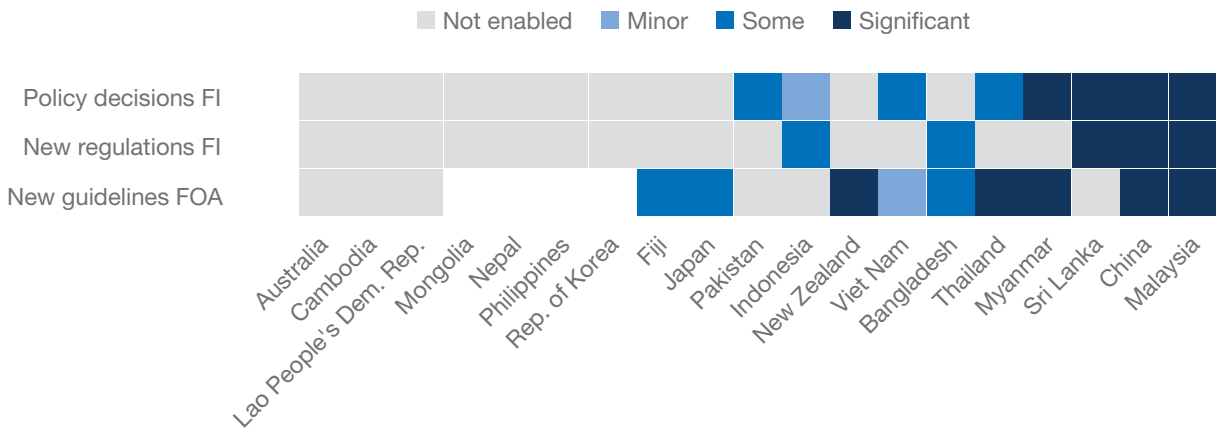
Additionally, the introduction of these advanced technologies has significantly increased public awareness of food safety and authenticity. Consumers, businesses and government authorities are now more knowledgeable about the importance of traceability and authenticity in the food supply chain, which has led to a cultural transformation in Viet Nam. Food safety and quality are now given greater priority, resulting in more transparent and accountable food systems.

2.4. Developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication

Overall participation in the RCA FS programme enabled some increase in new or modified regulations, policy decisions and interventions, and new or modified guidelines or protocols that support food irradiation and/or origin authentication technology. However, there was some variation between different SPs about the extent to which harmonized standards, guidelines and protocols were developed and adopted. Participation in the RCA FS programme resulted in a slightly higher contribution to guidelines about food origin authentication, but this was only slightly higher than for new or modified policy decisions.

In two SPs (China and Malaysia), there have been significant contributions from the RCA FS programme to all three areas (i.e. guidelines and protocols, regulations, and policy decisions and interventions (Fig. 4)). Four other SPs identified a significant contribution to one or two areas of harmonized standards. This variation reflects varying levels of effectiveness across SPs, recognizing that baseline levels of development and the programme's specific contributions vary by SP.

FIG. 4. The RCA FS programme's contribution to developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication.



For example, Myanmar's participation in the RCA FS programme has facilitated key policy decisions regarding food irradiation. A notable example is the enactment of Directive 8/2022 by the Myanmar Food and Drug Board of Authority, which outlines the labelling requirements for any food processed using ionizing radiation technologies.[3] The directive aims to enhance consumer awareness by providing clearer information about the quality, safety and health aspects of prepackaged food, facilitating traceability and promoting compliance with local and international standards.

In Japan, participation in the RCA FS programme has significantly contributed to shaping the country's policies and protocols regarding food origin authentication. A relevant example is the enactment, in 2014, of the Act on the Protection of the Names of Specific Agricultural, Forestry, and Fishery Products and Foodstuffs, commonly referred to as the geographical indications (GI) Act. The primary aim of the policy is to identify and safeguard a range of agricultural products originating from specific regions or localities, whose quality or distinct characteristics are intrinsically linked to their geographical origins. This Geographical Indication (GI) protection is recognized as intellectual property, enhancing both the value for producers and the trust of consumers.

[3] To access the Directive 8/2022 by the Myanmar Food and Drug Board of Authority, use https://www.myanmartradeportal.gov.mm/attachment/1179/download

2.5. Enhanced and effective application of irradiation and nuclear technologies, including commercial treatment capacities for an expanding range of food products

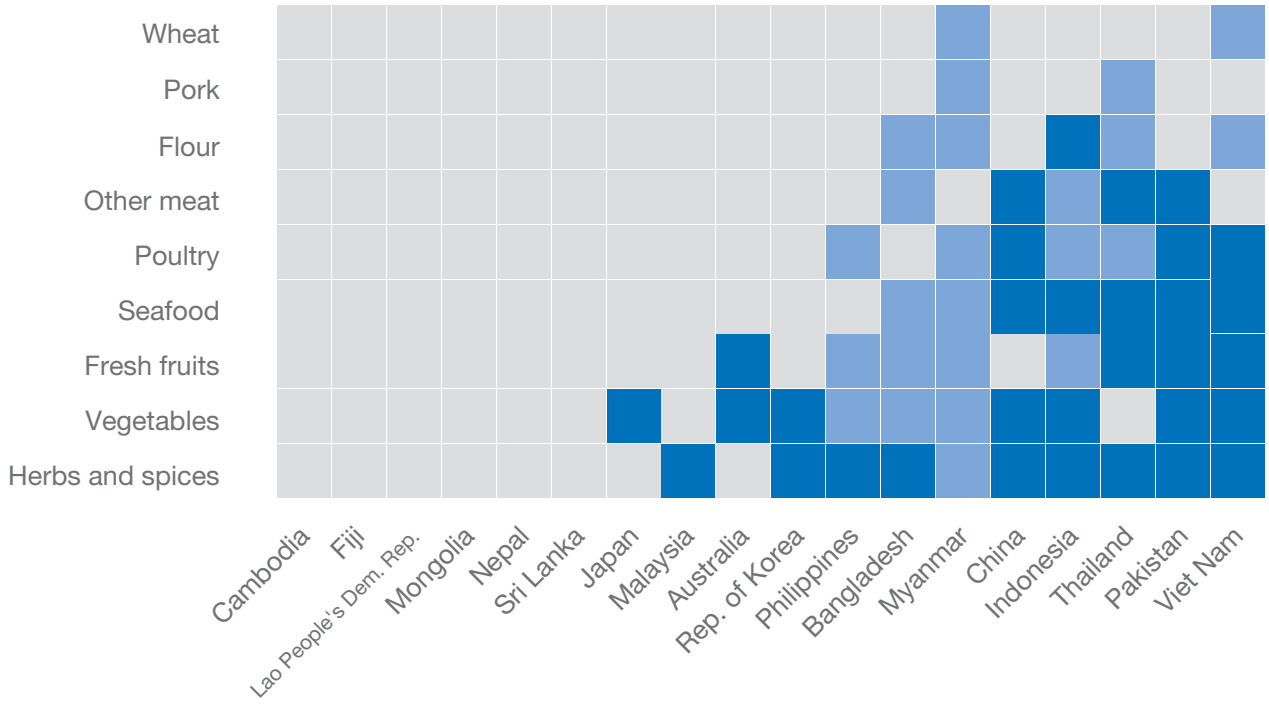
The RCA FS programme has effectively supported the application of irradiation and nuclear technologies for food safety and origin authentication in a substantial number of participating SPs. Eight SPs indicated broad commercial application of food irradiation and/or food origin authentication. Other countries have demonstrated the expansion of irradiation use for select food products or within specific sectors. However, several countries have yet to implement these technologies, highlighting areas for future support and development.

Participating SPs identified that the RCA FS programme had contributed more significantly to irradiation for research and development purposes than domestic or export applications. This suggests that while the programme plays a role across all three dimensions, its influence on domestic consumption and export of irradiated food is perceived as more limited.

2.5.1. Food irradiation

China, India, Republic of Korea, Thailand and Viet Nam each have more than five irradiation facilities but not all irradiate food commercially. Data available up to the end of 2023 indicate that China irradiates the most food on an annual basis (>1 million tonnes), followed by Viet Nam and India (both >100 000 tonnes) and Australia (>10 000 tonnes). Therefore, several countries in the region have commercial treatment capacities with at least four SPs irradiating significant quantities of foods each year. Countries with the most extensive application of irradiation technologies are Myanmar, which irradiates eight food types, followed by Indonesia, Thailand and Viet Nam, each irradiating seven food types (Fig. 5). The most commonly irradiated foods were herbs, spices, vegetables and fresh fruit. This distribution highlights the variety of irradiated foods and the varying levels of commercial application across participant countries.

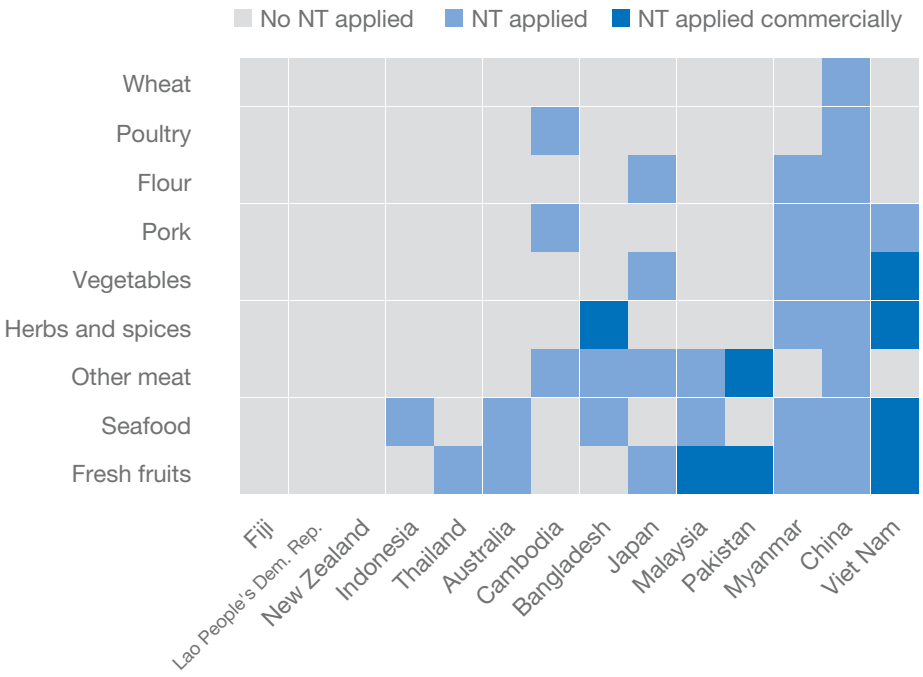
FIG. 5. Types of food that are irradiated and irradiated for commercial purposes (food irradiation) by country.



2.5.2. Food origin authentication

The countries that have adopted nuclear techniques for the widest range of food types include China, which applies these methods to all food categories listed, followed by Myanmar (six food types), Viet Nam (five food types), and Japan (four food types) (Fig. 6). The most commonly irradiated foods were vegetables, herbs and spices, seafood and fresh fruit.

FIG. 6. Types of food that are irradiated and irradiated for commercial purposes (food origin authentication) by country. Note: NT stands for nuclear techniques used for food origin authentication.



Malaysia utilizes nuclear techniques to verify the authenticity and origin of a wide range of high-value food products. In the case of products such as honey, edible bird's nest and fresh fruits, nuclear techniques enable the confirmation of their geographical origin, preventing fraudulent practices where products are falsely marketed to increase profits. In the meat industry, these methods help ensure the authenticity of halal products, which ensures compliance with religious and regulatory standards and strengthens consumer confidence. In the seafood sector, these techniques allow differentiation between farmed and wild-caught products, reducing fraudulent labelling practices. Through these applications, nuclear technology enhances food safety, consumer protection and market integrity in Malaysia.

Viet Nam now operates four facilities dedicated to food origin authentication, three of which are government owned. Since 2019, these facilities have significantly advanced the application of nuclear technologies for food origin authentication, with a particular focus on stable isotope analysis techniques. These methods have proven highly effective in providing precise results for determining the geographical origin and authenticity of a wide variety of food products. Stable isotope analysis is widely utilized to determine the origin of herbs, spices and fresh produce (such as apples, tomatoes, peppers and leafy greens). This advanced analytical technique allows Vietnamese authorities to verify whether imported products genuinely originate from their declared sources or have been fraudulently substituted with products from regions with lower safety standards or lower production costs. Additionally, stable isotope analysis plays a crucial role in verifying the authenticity of pork and seafood products — an especially

significant application for Viet Nam, as black tiger shrimp represents a major export commodity. The adoption of stable isotope techniques has also enabled the precise detection of C4 sugar adulteration in honey, another key agricultural product for the country.

2.6. Economic benefits[4]

A social cost-benefit analysis was conducted to estimate the economic impacts of the food safety RCA activities being evaluated. The analysis estimated the incremental (additional) costs of the food safety RCA activities and compared these to the incremental benefits enabled by those activities. The estimates are of the benefits and costs associated with technical cooperation in food irradiation and nuclear techniques for food origin authentication achieved under the RCA FS programme, compared to a hypothetical situation with no RCA programme.

The analysis used data from the survey of experts, together with administrative and cost data provided by the IAEA and public data and information from other sources. It estimated the costs and benefits that occurred between 1999 to 2023. Costs and benefits were analyzed as annual time series and adjusted for timing, using discounting to convert values occurring at different points in time into present values (based in 1999).

Estimated benefits that could be quantified reflect the costs of foodborne illnesses and food waste avoided due to greater uptake and use of food irradiation in RCA SPs that were enabled by the food safety RCA activities. Additional potential benefits, including increased exports and environmental benefits, could not be quantified, so the benefits enabled by RCA activities have probably been underestimated in our analysis.

Costs represent the opportunity costs arising from committing resources of the IAEA and RCA SPs to RCA related activities. They include costs directly associated with RCA activities and in-kind (non-monetary) contributions of SPs to support RCA activities.

Due to the indirect relationship between the RCA activities being evaluated and the use of food irradiation that generates benefits, it is not possible to estimate a dollar value of benefits associated with the RCA activities. Instead, many scenarios were analyzed, reflecting a range of assumptions about the impacts of the RCA activities, to test how likely it was that these activities enabled benefits that exceeded their costs.

[4] Due to using a similar framework to prior evaluations of RCA activities, this section includes similar text to prior publications including the Social and Economic Impact Assessment of the RCA Programme Non-destructive Testing Case Study [8].

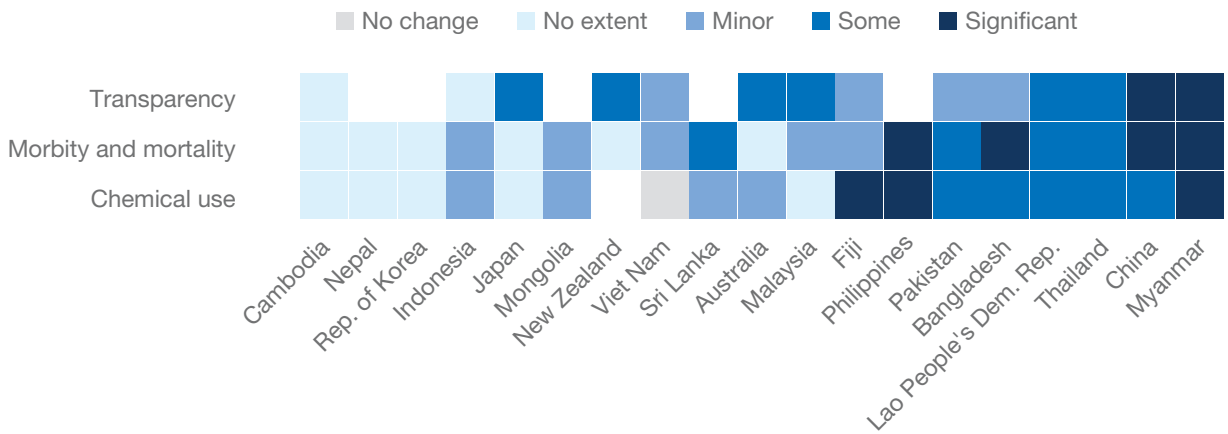
The analysis results indicate that the RCA delivered good economic outcomes, with estimated benefits enabled by the food safety activities exceeding estimated costs in 72% of scenarios that were tested, including under relatively conservative assumptions about impacts. Overall, there is good evidence that the RCA activities contributed to changes in policies and the uptake of food irradiation. These changes are likely to have improved food safety outcomes and reduced the associated costs of foodborne illnesses and food waste.

This analysis of costs and benefits is retrospective and is based on actual outcomes under the RCA programmes between 1999 and 2023 versus what was estimated to have happened in the absence of the RCA in that period. These results should not be used to make decisions about future activities under the RCA or to decide whether their scale should be increased or decreased. Full details of the economic analysis are provided in Annex VII.

2.7. Health and environmental benefits

The RCA FS programme is generally perceived as effective in supporting some health and environmental benefits (Fig. 7). Participants identified that the programme has notably reduced morbidity and mortality from foodborne illnesses in eight SPs. Other impacts included moderate reductions in chemical usage post-harvest, which lowers soil and water contamination and improves transparency in the agricultural-food supply chain through food origin authentication.

FIG. 7. Expert perceptions of RCA FS programme's contribution on health and environmental benefits (2000–2023).



In Malaysia, the programme has strengthened the market competitiveness of Malaysian food products, particularly high value items such as honey, edible bird's nest, seafood and fruits, by enhancing their credibility and marketability. This has created opportunities for local producers to access premium domestic and international markets, thereby increasing profitability and fostering export growth. Additionally, the programme has mitigated financial losses from counterfeit products, allowing producers to safeguard their brand integrity and maintain consumer trust. Moreover, it has stimulated investment in research, technology and infrastructure, fostering innovation and modernization within the food industry.

In another example, food irradiation has emerged in Thailand as an alternative technology for safe food production, increasing the safety of consumed products such as herbal supplements and fermented pork. By effectively reducing foodborne illnesses, irradiation offers a significant potential in decreasing morbidity, particularly if its use expands to more local fermented food items.

Economically, irradiating food products has boosted the domestic market and enhanced Thailand's competitiveness in international markets by meeting the stringent food safety standards of certain fresh agricultural products, particularly in export destinations such as Australia, New Zealand and the United States of America.

From an environmental perspective, irradiation offers Thailand a sustainable post-harvest treatment solution, particularly for the export of fresh fruits. The technology now plays a crucial role in reducing the need for chemical treatments, which can have detrimental effects on the environment. While irradiated fresh fruits constitute a small portion of total exports, as irradiation technology continues to expand, its broader adoption could further decrease reliance on harmful chemicals in agricultural exports, contributing to more environmentally friendly food production and exportation practices.

3.

Conclusion

The RCA FS programmes have supported significant gains in the development and application of nuclear techniques to improve SPs food safety and control systems for the benefit of consumers and trade. The social and economic impact assessment identified substantial contributions across multiple impact areas, including training, research and development, raising awareness, establishing standards, expanding technology applications and supporting health and environmental benefits. The social cost-benefit analysis estimated that the RCA FS programme likely created more economic value than it consumed between 1999 and 2022.

Pre-defined performance criteria were agreed upon with IAEA and SP experts to provide an evaluative framework for the impact assessment (Tables VII–1– VII–17, Annex VII). Based on the evidence provided by the IAEA and SPs, the RCA's impacts meet standards for **excellent performance** across one impact domain (established infrastructure and improved national R&D). Further, it achieved **good performance** across six impact domains (national trained personnel; raised awareness and understanding; harmonized standards, guidelines and protocols; enhanced and effective application; economic benefits; health and environmental benefits).

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Annex I: Food safety under RCA in Thailand – case example

I–1. Background

The Office of Atoms for Peace (OAP), established in 1961, was the first governmental organization responsible for nuclear and radiation research in Thailand. Food irradiation research commenced in the country in 1963 with the formation of the Food Irradiation Research Group at the OAP, with early studies primarily focusing on the safety of irradiated food. Between 1985 and 1987, the OAP received financial assistance from Canada to establish the first governmental food irradiation plant, which utilized Co-60 as the radiation source.

In the same decade, Thailand joined the food safety (FS) programme under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA). This technical collaboration played a crucial role in training personnel on food irradiation, as well as enhancing confidence in the adoption of the new technology and supporting the further expansion of commercial scale operations towards the end of the decade.

I–2. Strengthened national capacity

Cooperation under the RCA FS programme has played a key role in training national personnel on food irradiation, particularly staff at the OAP in the past and more recently, at Thailand Institute of Nuclear Technology (TINT). Approximately 50 national personnel have received technical training under the RCA, covering various aspects of food irradiation. This training has included, but is not limited to, electron beam and X ray technology, microbiological safety, sanitary and phytosanitary treatments, quality assurance and control, as well as the commercial applications and public awareness of food irradiation.

The knowledge exchange facilitated through the RCA FS collaboration has also played a significant role in advancing and expanding national research on food irradiation, particularly in specialized areas such as food irradiation for immunocompromised individuals and food irradiation in application in emergency settings.

I–3. Enhanced infrastructure and technology adoption

The capacity development supported by the RCA FS programme enhanced the knowledge and understanding of national personnel regarding e-beam and X-ray technologies. This advancement paved the way for initiating a feasibility study for developing related infrastructure in the country. The strengthened

human capacity contributed to establishing other essential facilities for specialized processes, such as dosimetry and microbial assays.

Today, Thailand utilizes irradiation technology across three government facilities for various food products and purposes. These include, among others, the elimination of microorganisms in herbs, spices and frozen seafood to enhance food safety for both domestic consumption and export, as well as meeting phytosanitary requirements for the export of fresh fruits to countries such as Australia, New Zealand and the United States of America. A notable success story is the use of irradiation for naem, a fermented pork product. In this product, irradiation is employed to eliminate potential microorganisms and extend shelf life by delaying the development of acidity. Naem has become the country's most successful irradiated food product, and it is widely available in popular convenience stores, reflecting the high level of consumer trust in the product.

I–4. Raised awareness and understanding

While the development of food irradiation technology in Thailand has not faced significant challenges, its practical application has. Limited public awareness and acceptance of food irradiation have hindered the widespread adoption of the technology. However, through collaboration under the RCA, the country has gradually made progress in engaging various stakeholders, achieving some success in raising awareness and fostering greater acceptance over time.

Participation in the knowledge exchange opportunities provided by the RCA FS programme has played a crucial role in disseminating information and raising awareness about food irradiation. Notably, involving a wide range of stakeholders from diverse fields, such as medical nutritionists, in the RCA training and workshops has been instrumental in expanding knowledge about the potential benefits of food irradiation across multiple areas of expertise.

As a result, the irradiation of certain products, such as herbal supplements and naem, has gained increasing popularity. To build on this progress, TINT has recently launched a programme that raises awareness to engage local food producers and small and medium enterprises in food irradiation. The programme includes awareness seminars and provides free irradiation trials. This initiative has successfully attracted new participants to food irradiation. However, the long term viability of these products is often influenced by the economic conditions of the participant companies and the broader national economy.

I–5. Social and economic effects

Collaboration under the RCA FS programme has been pivotal in enhancing Thailand's human capacity and governmental infrastructure for food irradiation. Furthermore, the country has gained access to valuable knowledge dissemination opportunities that have significantly increased public awareness of the potential benefits of the technology. As a result, food irradiation has not only seen improved social acceptance but has also led to a range of social, economic and environmental impacts.

Food irradiation has emerged as an alternative technology for safe food production in Thailand, benefiting the safety of consumed products such as herbal supplements and fermented pork. By effectively reducing foodborne illnesses, irradiation offers a significant potential in decreasing morbidity, particularly if its use expands to more local fermented food items.

Economically, the ability to irradiate food products not only boosts the domestic market but also enhances Thailand's competitiveness in international markets by meeting stringent food safety standards of certain fresh agricultural products, particularly in export destinations such as Australia, New Zealand and the United States of America.

From an environmental perspective, irradiation offers a sustainable post-harvest treatment solution, particularly for the export of fresh fruits. The technology plays a crucial role in reducing the need for chemical treatments, which can have detrimental effects on the environment. While irradiated fresh fruits constitute a small portion of total exports, as irradiation technology continues to expand, its broader adoption could further decrease reliance on harmful chemicals in agricultural exports, contributing to more environmentally friendly food production and exportation practices.

Annex II: Food safety under RCA in Myanmar – case example

II–1. Background

Food irradiation emerged as a topic of global significance in the mid-20th century and promoted as an effective method to enhance food safety, extend shelf life and minimize post-harvest losses. During this period, Yangon University in Myanmar played a pioneering role in research on the effects of gamma irradiation on fresh fruits and chili, contributing to the early understanding of this technology's applications.

In 1999, Myanmar joined the food safety (FS) programme under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA). This initiative provided Myanmar with access to technical assistance, specialized equipment and training to evaluate the feasibility of food irradiation. By 2000, the country commenced the use of irradiation technology for food preservation and safety purposes, marking a significant step forward in its efforts to modernize food processing and reduce waste.

Although the implementation of food irradiation in Myanmar is on a small scale, the country has significantly benefited from the enhanced human capacity and technological advancements gained through its participation in the RCA FS programme.

II–2. Strengthened national capacity

One of the key accomplishments of the RCA FS programme in Myanmar has been the significant advancement of human resource development in food irradiation.

Before receiving support from the RCA FS programme, Myanmar faced considerable challenges due to the limited availability of qualified personnel in this area. Nevertheless, with the technical cooperation provided, a dedicated team of approximately ten members was able to participate in a series of hands-on regional training sessions, workshops and expert missions,[1] significantly enhancing their expertise in food irradiation. Notably, national experts were trained in a range of critical topics, including electron beam and X ray technology, microbiological safety, sanitary and phytosanitary treatments, quality assurance and control, and the commercial applications and public awareness of food irradiation, among others. This significant development in human capacity has also enabled Myanmar to produce over 30 high-quality research outputs and publications on the subject, mainly focusing on the use of irradiation for agricultural products such as rice, beans and pulses—key export commodities for the country.

[1] Some of the most significant projects through which capacity development was achieved include RAS5061, RAS5062, RAS5071, RAS5078, RAS5081 and RAS5087.

II–3. Enhanced infrastructure and technology adoption

A Gamma Chamber 5000 was installed at the Department of Atomic Energy (DAE) in 2000. Through the cooperation established under the RCA FS programme, national scientists have conducted numerous gamma irradiation projects using this facility, including research on food irradiation.

Currently, Myanmar is utilizing the Gamma Chamber 5000 for food irradiation research, focusing on improving the safety of key agricultural products, such as herbs, spices and fresh fruits and vegetables, which are of significant value to the country.

Furthermore, since 2013, Myanmar has developed a strategic plan to enhance its radiation processing, research and development activities. This plan includes upgrading the existing gamma irradiation facility and eventually establishing a new electron beam facility. A project team is already in place to lead this development, which is expected to support both research and semi-commercial operations. With the collaboration of the RCA FS programme, the country is in the process of establishing a high-performance liquid chromatography (HPLC) laboratory for contaminated food analysis.

II–4. Raised awareness and understanding

Participation in national and regional training sessions and workshops facilitated by the RCA FS programme has significantly contributed to disseminating knowledge and raising awareness in Myanmar. The country has organized awareness seminars for various audiences, including universities, government officials and other stakeholders. These efforts have enhanced the general understanding of radiation processing technologies, including food irradiation and their impact on food safety and security.

II–5. Policy influence

Myanmar's participation in the RCA FS programme has facilitated key policy decisions regarding food irradiation. A notable example is the enactment of Directive 8/2022 by the Myanmar Food and Drug Board of Authority, which outlines the labelling requirements for any food processed using ionizing radiation technologies.[2] The directive aims to enhance consumer awareness by providing

[2] To access the Directive 8/2022 by the Myanmar Food and Drug Board of Authority, use https://www.myanmartradeportal.gov.mm/attachment/1179/download

clearer information about the quality, safety and health aspects of prepackaged food, facilitating traceability and promoting compliance with local and international standards.

II–6. Social and economic effects

Myanmar's adoption of food irradiation technology has progressed more slowly than some neighbouring countries due to factors such as limited initial infrastructure, a shortage of skilled human resources and a lack of public awareness regarding the applications and potential benefits of food irradiation. Currently, the country is in the early stages of using food irradiation exclusively for research purposes, and as such, the broader social and economic impacts of this technology are yet to be fully realized. However, with the enhanced human capacity and technological advancements supported by the RCA FS programme, it is anticipated that the use of food irradiation for pest control and shelf life extension will increase in the coming years, ultimately contributing to a reduction in foodborne illnesses.

Annex III: Food safety under RCA in Malaysia – case example

III–1. Background

Malaysia's participation in the food safety (FS) programme under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA) began in 1980. However, it was not until 2015 that the country began utilizing nuclear techniques for food origin authentication.

During the first decades of collaboration under the RCA FS programme, Malaysia's focus was largely centred on food irradiation and conventional food safety practices. While these initiatives significantly enhanced food safety standards, they were insufficient for addressing the increasingly prominent challenges of food fraud and origin verification. The available analytical tools could not reliably distinguish between food products with similar physical and chemical properties but differing origins, and there was a notable lack of technical expertise in food authentication using nuclear techniques. The capacity development fostered under the RCA FS programme, together with the introduction of stable isotope analysis and nuclear techniques, marked a significant milestone in overcoming these challenges and ensuring the authenticity of Malaysian food products by applying advanced nuclear methodologies.

III–2. Strengthened national capacity

A key contribution of the RCA FS programme in Malaysia was providing specialized technical training to enhance the country's capacity in food origin authentication. Overall, a team of approximately ten national personnel were trained on robust analytical approaches such as stable isotope ratio analysis, elemental profiling and advanced statistical methods (e.g. multivariate data analysis). Delivered by leading regional experts, these sessions equipped Malaysian personnel with the skills and knowledge necessary to implement reliable and modern food authentication systems using nuclear and related techniques, addressing challenges in food fraud detection effectively.

In addition to providing technical knowledge on the use of advanced analytical methodologies and equipment, the RCA FS programme also provided guidance in data interpretation, enabling national researchers to derive accurate and meaningful insights from complex datasets. The programme also supported strengthening research publications by providing international expertise and feedback, ensuring the outputs met international standards. These efforts collectively enhanced the quality and credibility of Malaysia's research in food origin authentication, facilitating its dissemination and impact within the global scientific community.

III–3. Enhanced infrastructure and technology adoption

Participation in the RCA FS programme significantly contributed to the establishment and development of Malaysia's two government facilities for food origin authentication, which include stable isotope and elemental analysis capabilities. In particular, the programme provided essential guidance on the technical specifications required to develop these infrastructures and recommendations on the equipment needed to ensure the facilities were equipped with advanced analytical tools suitable for food authentication. The programme also offered advice on designing the laboratory environment and optimizing the arrangement of equipment to meet international standards.

Malaysia now utilizes nuclear techniques to verify the authenticity and origin of a wide range of high-value food products. In the case of products such as honey, edible bird's nest and fresh fruits, nuclear techniques enable the confirmation of their geographical origins, preventing fraudulent practices where products are falsely marketed to increase profits. In the meat industry, these methods help ensure the authenticity of halal products, which ensures compliance with religious and regulatory standards and strengthens consumer confidence. In the seafood sector, these techniques allow the differentiation between farmed and wild caught products, reducing fraudulent labelling practices. Through these applications, nuclear technology enhances food safety, consumer protection and market integrity in Malaysia.

III–4. Raised awareness and understanding

Participation in the RCA FS programme has been crucial in disseminating information and raising awareness about food origin authentication in Malaysia. The programme contributed to the establishment of various research collaborations involving multiple ministries,[1] allowing government agencies to understand better and implement nuclear techniques for food origin authentication. Consumers were also educated on the topic through talks and exhibitions at major national events, raising awareness about the role of nuclear techniques in verifying food authenticity and strengthening confidence in the safety and quality of Malaysian food products.

[1] The ministries include, among others, Ministry of Science, Technology and Innovation, Ministry of Health, Ministry of Agriculture and Food Security, Ministry of Higher Education and Ministry of Plantation and Commodities.

III–5. Social and economic effects

The development and implementation of food origin authentication under the RCA FS programme have yielded significant and positive social impacts in Malaysia. It has bolstered consumer confidence by providing dependable methods to verify the authenticity and origin of food products, particularly high value items such as honey, seafood and premium fresh fruits. Moreover, the programme has contributed to preserving cultural and religious values by addressing food fraud issues that conflict with societal norms, particularly in the context of halal compliance. Public education initiatives and exhibitions have raised awareness regarding food fraud, empowering consumers to make informed decisions.

From an economic perspective, the programme has strengthened the market competitiveness of Malaysian food products, particularly high value items such as honey, edible bird's nest, seafood and fruits, by enhancing their credibility and marketability. This has created opportunities for local producers to access premium domestic and international markets, thereby increasing profitability and fostering export growth. Additionally, the programme has mitigated financial losses from counterfeit products, allowing producers to safeguard their brand integrity and maintain consumer trust. Moreover, it has stimulated investment in research, technology and infrastructure, fostering innovation and modernization within the food industry.

Despite all these advances, challenges remain. Adopting advanced authentication techniques inevitably results in increased costs for producers, especially smaller businesses that could face difficulties making necessary investments in technology, training and compliance. The complexity of adapting to new methods and protocols can be overwhelming for stakeholders with limited resources or expertise. Furthermore, some consumers continue to express scepticism regarding the authenticity of certain products, particularly considering isolated instances of fraud. Despite these challenges, the overall impact of the RCA FS programme has mainly been positive, fostering trust, economic growth and cultural integrity within Malaysia's food systems.

Annex IV: Food safety under RCA in Viet Nam – case example

IV–1. Background

Until the second decade of the 2000s, Viet Nam faced a notable lack of scientifically validated methods for authenticating the origin of high value commodities, including honey, fruits, shrimp and rice. Instead, food origin authentication in the country primarily relied on traditional methods such as document verification, manual traceability systems (e.g. QR codes) and anti-counterfeit labelling. However, these methods proved inadequate in effectively addressing food fraud and ensuring the quality of agricultural products.

In 2018, Viet Nam joined the food safety (FS) programme under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA). Viet Nam's participation in the RCA FS programme represented a pivotal transition from conventional methods to advanced scientific techniques for food origin authentication, enhancing food safety and traceability.

IV–2. Strengthened national capacity

The RCA FS programme provided specialized workshops and hands-on training sessions, enhancing the expertise of Vietnamese scientists and technicians in the application of nuclear and related techniques for food origin authentication. This included comprehensive instruction in data analysis as well as the foundational principles of advanced techniques such as elemental analysis-isotope ratio mass spectrometry (EA-IRMS), inductively coupled plasma mass spectrometry (ICP-MS), and Fourier transform infrared spectroscopy (FTIR). The training opportunities offered through the RCA FS programme enabled Vietnamese researchers to acquire proficiency in stable isotope techniques, ensuring that food authentication could be conducted with a high degree of precision while simultaneously contributing to the development of robust and reliable food safety systems within the country.

The programme also facilitated international collaboration, providing Vietnamese researchers with the opportunity to engage with global best practices in food safety and origin authentication. This collaboration allowed Vietnamese experts to learn from the experiences of other nations, thus accelerating the application of isotopic analysis for food origin authentication in the local context.

Participation in the RCA FS programme significantly advanced high-quality national research on food origin authentication, contributing to the global body of knowledge on the subject and highlighting Viet Nam's progress in this field. A prime example of this contribution is the research initiative on honey adulteration, which utilizes stable isotope techniques, such as $\delta^{13}C$ analysis, to detect C4 sugar adulteration in honey. The results of this research have been disseminated internationally, elevating Viet Nam's reputation in the domain of food safety research.

IV–3. Enhanced infrastructure and technology adoption

In addition to fostering the development of human resources and research within the country, the support provided by the RCA FS programme enabled the procurement of specialized laboratory equipment for food safety analysis and evaluation. These facilities were outfitted with advanced technologies for food origin authentication, including nuclear and isotopic testing methods, which have played a crucial role in advancing the country's food safety initiatives.

Viet Nam now operates four facilities dedicated to food origin authentication, three of which are government owned. Since 2019, these facilities have significantly advanced the application of nuclear technologies for food origin authentication, with a particular focus on stable isotope analysis techniques. These methods have proven highly effective in providing precise results for determining the geographical origin and authenticity of a wide variety of food products. Stable isotope analysis is widely utilized to determine the origin of herbs, spices and fresh produce, such as apples, tomatoes, peppers and leafy greens. This advanced analytical technique allows Vietnamese authorities to verify whether imported products genuinely originate from their declared sources or have been fraudulently substituted with products from regions with lower safety standards or lower production costs. Additionally, stable isotope analysis plays a crucial role in verifying the authenticity of pork and seafood products—an especially significant application for Viet Nam, as black tiger shrimp represents a major export commodity. The adoption of stable isotope techniques has also enabled the precise detection of C4 sugar adulteration in honey, another key agricultural product for the country.

IV–4. Policy influence

As a result of Viet Nam's participation in the RCA FS programme, Vietnamese authorities have gained a comprehensive understanding of the importance of the use of nuclear scientific methods for food traceability and origin authentication. Consequently, the programme has played a vital role in shaping Viet Nam's strategies and policies regarding food safety. The country has established a robust framework for food safety management, ensuring that food production, processing and distribution are aligned with international best practices to protect consumers and facilitate trade. Today, Viet Nam has a national food safety programme that focuses on both food safety and traceability. The programme outlines comprehensive measures for food testing and certification, ensuring that food products meet the highest safety standards before entering the market. This initiative has played a key role in strengthening the overall food safety system of Viet Nam.

IV–5. Social and economic effects

The development and adoption of food origin authentication through nuclear techniques under the RCA FS programme has generated significant social and economic impacts in Viet Nam, benefiting multiple sectors of society.

One of the primary advantages of the adoption of food authentication technology has been the enhancement of consumer confidence in the products available in the national market. Vietnamese consumers can now rely on the assurance that the food they purchase, whether domestic or imported, meets international safety standards. The use of stable isotope techniques in verifying the origin of products, such as honey, apples or pork, has provided consumers with the confidence that these products are free from adulteration and mislabelling, fostering a sense of trust in the integrity of the food supply.

Additionally, the introduction of these advanced technologies has significantly increased public awareness of food safety and authenticity. Consumers, businesses, and government authorities are now more knowledgeable about the importance of traceability and authenticity in the food supply chain, which has led to a cultural transformation in Viet Nam. Food safety and quality are now given greater priority, resulting in more transparent and accountable food systems.

In terms of economic impact, the most notable change has been the significant enhancement of the export potential of national products. The implementation of nuclear technologies for food origin authentication has greatly improved the country's ability to meet international food safety standards, thereby opening doors to expanded exports of agricultural products, such as seafood, rice and fresh fruits. By ensuring that food products comply with stringent international standards for authenticity, Viet Nam is now able to access higher value markets in Asia, Europe and North America, thus enhancing its global trade opportunities. Furthermore, the widespread use of nuclear techniques and the establishment of advanced laboratory facilities have created new job opportunities within Viet Nam, particularly in areas related to food safety, laboratory management and scientific research.

However, the implementation of food origin authentication technologies is also associated with some negative economic impacts. The most notable of these is the significant initial investment required for the establishment of the necessary technical infrastructure. While the long term benefits, such as enhanced food safety and improved access to export markets, outweigh these costs, small and medium sized enterprises could face challenges in bearing these substantial upfront investments without external funding or support. Additionally, the shift toward nuclear authentication methods could have a disruptive effect on smaller agricultural producers who are unable to afford these advanced technologies. This transition could present difficulties for small scale producers, who could struggle to maintain competitiveness with larger, technologically advanced companies that can better absorb the costs of these innovations.

Annex V: Food safety under RCA in Japan – case example

V–1. Background

Japan's use of technologies to determine the geographical origin of agricultural products began in the late 1990s, initially focusing on trace element analysis. However, it was not until 2010 that the country actively adopted nuclear technologies, such as stable isotope ratio analysis, for identifying the origins of agricultural, livestock and fisheries' products. The development of these technologies was driven by the growing issue of food adulteration and mislabelling in the country, particularly in products such as rice, honey, beef and eel.

In 2012, Japan joined the food safety (FS) programme under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA).[1] Participation in the programme facilitated capability development and international collaboration, making the country one of the global leaders in utilizing nuclear technologies for food origin authentication.

V–2. Strengthened national capacity

The RCA FS programme provided Japanese scientists with the opportunity to participate in a variety of training courses, greatly contributing to the improvement of their technical capabilities in the application of nuclear techniques for food origin authentication. For example, a total of five training courses were offered under project RAS5081, including both introductory and advanced analytical techniques, as well as several sessions on chemometrics.

The programme also facilitated international collaboration among research institutes, fostering an environment where countries facing similar challenges, such as rice and honey adulteration, could share their technological advances and collaboratively develop potential solutions. Through this international cooperation, a reliable and comprehensive database of authentic samples for rice and honey was created. Indeed, participation in the RCA FS programme facilitated the collection and analysis of authentic rice samples from fourteen countries and honey samples from five countries, contributing to the creation of a thorough sample database for the Asia and the Pacific region.

[1] Japan's first participation in the RCA FS programme was under project RAS5062, Building Technological Capacity for Food Traceability and Food Safety Control Systems through the Use of Nuclear Analytical Techniques, in Hanoi, Viet Nam.

V–3. Enhanced infrastructure and technology adoption

Japan currently operates four facilities dedicated to food origin authentication, one of which is government owned. Notably, these facilities were established before joining the RCA FS programme and were already equipped with advanced technologies, including inductively coupled plasma mass spectrometry (ICP-MS), inductively coupled plasma optical emission spectrometry (ICP-OES), and isotope ratio mass spectrometry (IRMS).

Since 2012, the Research Centre for Advanced Analysis at the National Agriculture and Food Research Organization (NARO) has been the leading institution for research and development in food origin authentication in Japan, utilizing IRMS technology. Additionally, Japan's Food and Agricultural Materials Inspection Centre (FAMIC), an incorporated administrative agency, collaborates closely with the Ministry of Agriculture, Forestry and Fisheries (MAFF) for food safety and labelling oversight in the country. FAMIC conducts inspections mainly on items for which there is a large price difference between domestic and foreign products. It is estimated that FAMIC tests more than 5000 samples of commercially available food products each year using different analytical technologies, including DNA analysis, elemental analysis and stable isotope ratio analysis.

Japan is now a global and regional leader in utilizing nuclear technologies for food origin authentication. A key example of this leadership in ensuring the reliability of analytical methods for food origin authentication is its role in conducting proficiency testing. Specifically, as part of its RCA activities, Japan carried out a proficiency testing of EA-IRMS measurements of stable carbon and nitrogen isotopic compositions in matrix materials and organic compounds. This initiative involved 19 laboratories from Japan and other RCA Member States,[2] including research institutes and private companies, significantly enhancing the technical capabilities of stable isotope ratio analysis in the region. The results of the proficiency testing were summarized and disseminated by NARO, which contributed to the improvement of technology among both domestic and international research institutions.

V–4. Policy influence

The enhancement of human capability and technology adoption facilitated by participation in the RCA FS programme has significantly contributed to shaping Japan's policies and protocols regarding food origin authentication.

[2] Malaysia and Singapore.

In 2014, Japan introduced the Act on the Protection of the Names of Specific Agricultural, Forestry, and Fishery Products and Foodstuffs, commonly referred to as the Geographical Indications Act, which came into effect in 2015. The primary aim of this policy was to identify and safeguard a range of agricultural products originating from specific regions or localities, whose quality or distinct characteristics are intrinsically linked to their geographical origin. This geographical indication (GI) protection is recognized as intellectual property, enhancing both the value for producers and the trust of consumers.

In 2017, Japan further strengthened its commitment to transparency and consumer information by revising and enforcing its food labelling standards. Under the updated regulations, all processed foods manufactured or processed in Japan must include mandatory country-of-origin labelling for their primary ingredients. Specifically, the most predominant ingredient by weight (referred to as the subject ingredient) is required to be labelled with both its name and its country of origin. Considering this, it is crucial for the FAMIC and the broader food industry to implement effective measures for verifying the origin of ingredients, not only in raw materials but also in processed foods. As a result, the continuous development of scientific technologies for food origin authentication remains a key priority for the country.

V–5. Social and economic effects

The development of nuclear technologies for food origin authentication in Japan under the RCA FS programme has led to significant economic and social benefits for the country.

Despite the price disparity between domestically produced and imported agricultural products, Japanese consumers show a strong preference for domestic options, valuing their superior quality and safety standards. Furthermore, the GI system has proven to be an effective mechanism for safeguarding the names and reputations of regional products, thereby enhancing their competitiveness both within Japan and in international markets.

From a health perspective, instances of mislabelling and foodborne illnesses in Japan remain exceptionally rare. The advanced development of analytical techniques for determining the origin of food products by government and commercial laboratories has played a crucial role in minimizing mislabelling within the food industry. These advancements have significantly improved transparency across the food supply chain.

Annex VI: Survey analysis

VI–1. Summary

The IAEA's food safety online survey, conducted between August 2024 and October 2024 across 19 countries in the Asia-Pacific region (Australia, Bangladesh, Cambodia, China, Fiji, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, the Philippines, the Republic of Korea, Sri Lanka, Thailand and Viet Nam), evaluated the Regional Cooperative Agreement Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA) Food Safety (FS) programme from 2000 to 2023. The assessment focused on its social and economic impacts. There are six main key findings.

1. Nationally trained personnel

The RCA FS programme has significantly contributed to the training of national personnel and has received a **good** rating according to the agreed performance framework (Tables VIII–1– VIII–7, Annex VIII). The numbers of personnel trained and the types of training are:

- 259 in sanitary and phytosanitary treatment,
- 235 in quality assurance and quality control,
- 187 in electron beam and X ray technology,
- 63 in nuclear techniques for food authentication.

These represent only a portion of the total personnel trained, highlighting the programme's broad efforts to enhance State Parties' (SPs) capacities to implement food irradiation and origin authentication techniques.

2. Established infrastructure and improved national research and development for food irradiation and food origin authentication

The programme's support for infrastructure and national research and development (R&D) in food irradiation and origin authentication received an **excellent** rating.

- Between 2000 and 2023, approximately 490 research outputs were produced, advancing scientific knowledge and technical capabilities in food safety.
- Across the participating countries, 128 dedicated laboratory facilities exist, with 74% focusing on food irradiation. The survey indicates that 78% of these countries attribute some or significant development of government facilities for origin authentication to the RCA FS Programme.

3. Raising awareness

The programme achieved a **good** rating for raising awareness among governments, businesses and the public about the benefits of food irradiation and origin authentication. These efforts have enhanced knowledge and acceptance, although adoption levels vary by region.

4. Standards and protocols
The RCA FS Programme received a **good** rating for its contribution to developing harmonized standards and protocols for food irradiation and origin authentication. This work has supported regulatory changes and enhanced technological guidelines.

5. Enhanced and effective application of irradiation and nuclear technologies
Enhanced application of irradiation and nuclear technologies received a **good** rating, with over 90% of countries recognizing the programme's role in advancing commercial food treatment. However, some countries still face challenges in technology implementation.

6. Health and environmental benefits
The programme's contribution to health and environmental outcomes received a **good** rating, with notable impacts in reducing foodborne illnesses in eight countries. Other impacts included moderate reductions in chemical usage and improved transparency in the agricultural-food supply chain.

VI–2. Introduction

This report presents the findings of the Social and Economic Impact Assessment of the Food Safety (FS) programme of the Regional Cooperative Agreement (RCA) in Asia and the Pacific. The data that inform the analysis were collected through an online survey that was designed and piloted in July 2024 and deployed between August 2024 and October 2024. The respondents to the survey were national experts in the field of FS.

The national experts provided relevant information about several critical areas related to food irradiation and the use of nuclear techniques for origin authentication. They offered information on the capacity of trained personnel to manage all aspects of these processes, as well as the current state of infrastructure and recent advancements in research and development, particularly concerning facilities and technical capabilities. Additionally, they shared their perceptions on the awareness that governments, businesses and the public have about the benefits of food irradiation that the RCA programme has contributed to achieve in their countries.

Out of the 22 countries that are part of the RCA, **the report focuses on the 19 countries that participated in IAEA's FS online survey: Australia, Bangladesh, Cambodia, China, Fiji, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, the Philippines, the Republic of Korea, Sri Lanka, Thailand and Viet Nam.** The participation in the survey, and thus the countries, included in the analysis for each theme, is as follows:

Food Irradiation: 18 Government Parties (GPs) participated (Australia, Bangladesh, Cambodia, China, Fiji, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, the Philippines, the Republic of Korea, Sri Lanka, Thailand and Viet Nam).

Food origin authentication: 14 GPs participated (Australia, Bangladesh, Cambodia, China, Fiji, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Myanmar, New Zealand, Pakistan, Thailand and Viet Nam).

The analysis presents the outcomes from the countries that participated in the survey. However, it is essential to acknowledge that three of these countries — Cambodia, Fiji and Nepal— while being signatories to the RCA, have not been extensively engaged in the activities of the RCA FS programme. Consequently, the programme's impact on these countries' accomplishments across all evaluation metrics could be limited. It is therefore recommended that the findings in this report be interpreted with this context in mind.

The assessment of the social and economic impacts of the RCA FS programme involved pre-defining agreed performance criteria (aspects of social and economic impacts that were the focus of the evaluation) and standards (narratives describing four levels of performance – excellent, good, adequate and minor) (Table VI–1). These criteria and standards (detailed in Annex VIII) provided a transparent and robust framework for rating the impact of the RCA FS programme.

In particular, to understand the contribution of the RCA FS programme on social and economic indicators, the study analyzes the extent to which being part of the programme has enabled GPs to fulfill the following criteria.

Table VI–1. Criteria for food safety explored in the survey.

Criterion	Performance sub-criteria
National personnel trained in all aspects of food irradiation and/or use of nuclear techniques for origin authentication	As a result of RCA: ▶ National personnel are trained to carry out all aspects of food irradiation ▶ National personnel are trained to use nuclear techniques for origin authentication technology
Established infrastructure and **improved national R&D** for food irradiation and origin authentication	As a result of RCA: ▶ There is established infrastructure that includes the provision of laboratory facilities for food analysis, irradiation and/or food origin authentication ▶ There is improved national R&D capacity for food irradiation and/or food origin authentication (including market and trade trials)
Raised awareness and understanding among governments, businesses and the public about the value of food irradiation and origin authentication	As a result of RCA: ▶ Increased consumer acceptance of food irradiation and origin authentication ▶ Improved business perceptions about food irradiation and origin authentication ▶ Improved government perceptions about food irradiation and origin authentication

Criterion	Performance sub-criteria
Developed and adopted **harmonized standards, guidelines and protocols** for food irradiation and origin authentication	RCA enables: ▶ Regulations and policies that support food irradiation ▶ Guidelines and protocols for the use of origin authentication technology
Enhanced and effective **application of irradiation and nuclear technologies**, including commercial treatment capacities for an expanding range of food products	RCA enables: ▶ Expanding the use of irradiation to a wider range of food products ▶ Commercial use of food authentication
Health and environmental benefits	RCA enables: ▶ Reductions in morbidity and mortality from foodborne illnesses ▶ Reductions in chemical use post-harvest lowering soil and water contamination ▶ Improved transparency in the agricultural-food supply chain

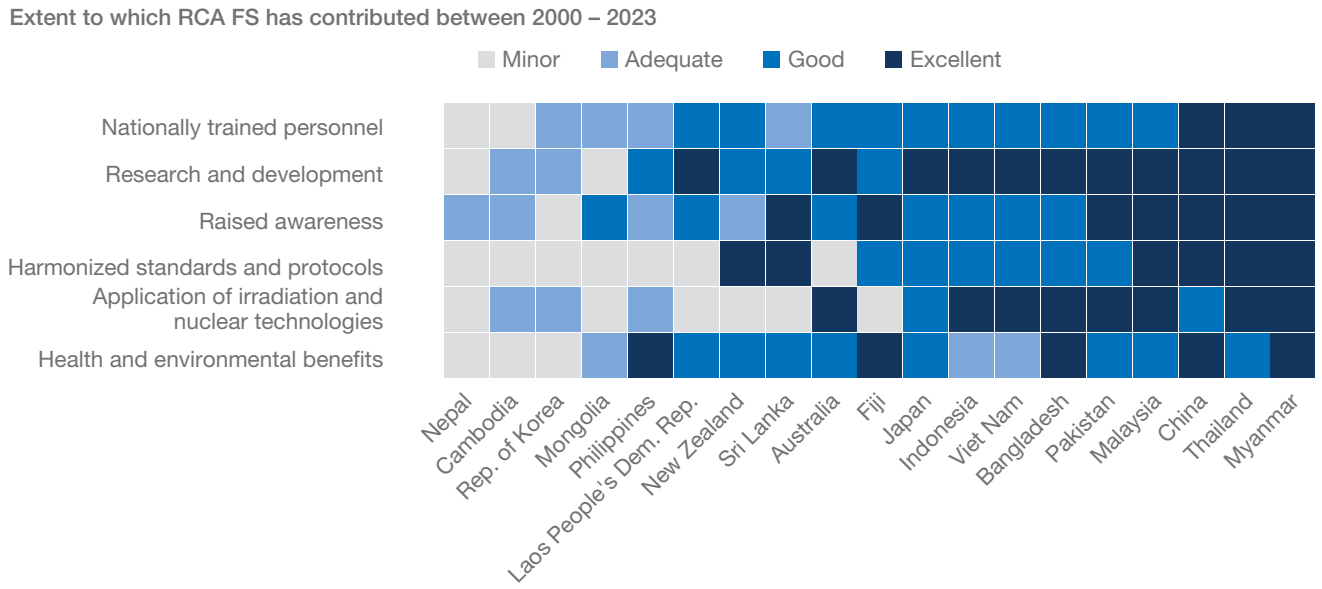
VI–3. Overall impact assessment of the RCA food safety programme by key performance areas

Based on the analysis and the pre-defined performance criteria—focused on social and economic impacts—and performance standards (ranging from excellent to minor), **the RCA FS programme has achieved an overall rating of good.** This rating reflects the programme's substantial contributions across multiple impact areas, including training, research and development, raising awareness, establishing standards, expanding technology applications and supporting health and environmental benefits.

The programme has made substantial strides in building local capacity, enhancing R&D, fostering awareness, supporting regulatory standards, expanding technology applications and contributing to health and environmental benefits.

Figure VI–1 below illustrates the performance ratings for each criterion across participating countries, providing a summary of the RCA FS programme's contributions from 2000 to 2023. This visual representation highlights the extent of progress in these key areas.

FIG. VI–1. Performance ratings of the RCA FS programme by country and criterion.



VI–4. Criterion 1: National personnel trained in all aspects of food irradiation and/or use of nuclear techniques for origin authentication

This section presents the results of the assessment on the extent to which the support of the RCA FS programme has enabled GPs to train national personnel in carrying out all aspects of food irradiation and in using nuclear techniques for origin authentication technology.

VI–4.1. Ratings and standards of Criterion 1

The standards (levels of performance) for the fulfilment of this criterion are as follows (Table VI–2):

Table VI–2. Ratings and standards of Criterion 1.

Rating	Standard
Excellent (exceeding expectations)	Participation in the RCA FS programme of the IAEA results in: ▶ An increase in in-country personnel trained to carry out **all** aspects of food irradiation; **and** ▶ An increase in in-country personnel trained to use nuclear techniques for origin authentication
Good (meeting expectations)	Participation in the RCA FS programme of IAEA results in: ▶ An increase in in-country personnel trained to carry out **all** aspects of food irradiation; **and/or** ▶ An increase in in-country personnel trained to use nuclear techniques for origin authentication
Adequate (meeting bottom-line expectations)	Participation in the RCA FS programme of IAEA results in: ▶ An increase in in-country personnel trained to carry out **some** aspects of food irradiation
Minor (not meeting expectations)	Standard for adequate not met

Based on the evidence provided by the IAEA and GPs, the RCA demonstrates an **overall good rating in meeting the "nationally trained personnel" criteria.**[1] This indicates that, in general, the programme is aligned with good standards in terms of training and capacity building at a national level. The specific standards for the programme in each participating country are outlined below.

VI–4.1.1. Breakdown of ratings by country for Criterion 1

- **Excellent:** China, Myanmar and Thailand (3 GPs);
- **Good:** Australia, Bangladesh, Fiji, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, New Zealand, Pakistan and Viet Nam (10 GPs);
- **Adequate:** Cambodia, Mongolia, Nepal, the Philippines, the Republic of Korea and Sri Lanka (6 GPs).

Cambodia and Nepal reported that national personnel have not been trained by the RCA in any topics related to food safety between 2000 and 2023. The lack of training is expected because while being signatories to the RCA, Cambodia and Nepal have not been extensively engaged in the activities of the RCA AQM programme.

VI–4.2. Nationally trained personnel

This section presents the number of national personnel who have received training or participated in sessions on topics related to food irradiation and food origin authentication as part of the RCA FS programme between 2000 and 2003.

[1] To calculate the overall performance, the rankings from each SP are summed and divided by the total number of GPs to find the mean. The ceiling function is then applied to round the mean up to the nearest whole number.

The relevance of this information lies in assessing the RCA FS programme's contribution on building national expertise and technical capacity in critical areas of food safety.

VI–4.2.1. Trained personnel in food irradiation

Based on administrative data provided by the IAEA, the RCA FS programme offers training primarily in the following areas, each crucial for the safe and effective application of food irradiation:

- **Commercial applications:** focuses on the practical use of irradiation technology for food preservation, extending shelf life and reducing food waste.
- **Electron beam and X ray technology:** covers advanced methods for irradiating food that are efficient, safe and increasingly favoured in commercial settings for their precision and reduced processing time.
- **Microbiological safety:** ensures that personnel are equipped to apply irradiation methods to eliminate pathogens and reduce microbial load, enhancing food safety for consumers.
- **Public information on the use of irradiation:** emphasizes the importance of transparency and public awareness regarding the safety and benefits of food irradiation, which is vital for consumer acceptance.
- **Quality assurance and quality control systems:** trains personnel to implement rigorous standards to maintain consistent product quality and to ensure the safety of irradiated food.
- **Quarantine security in trade:** addresses the use of irradiation to meet international trade standards by controlling pests in food exports, thereby facilitating safe and compliant trade.
- **Sanitary and phytosanitary treatment:** focuses on the use of irradiation to control pests and pathogens, helping countries comply with international sanitary and phytosanitary standards.

Table VI–3 below shows the total number of nationally trained personnel in each aspect of food irradiation. As shown, the area with the highest number of trained personnel is sanitary and phytosanitary treatment, with a total of 259 personnel trained across all participating countries in the programme. This is followed by quality assurance and quality control systems and electron beam and X ray technology, with 235 and 187 personnel trained, respectively.

The SPs reported that approximately 135 personnel have been trained in additional topics. These topics include materials modification, strengthening adaptive change strategies for food security through the use of food irradiation, radiation interactions, principles of radiation detectors and detection methods.

Table VI–3. Total number of nationally trained personnel in each aspect of food irradiation.

Area	Personnel trained
Sanitary and phytosanitary treatment	259
Quality assurance and quality control systems	235
Electron beam and X ray technology	187
Commercial applications	176
Public information on the use of irradiation	149
Other topics	135
Quarantine security in trade	108
Microbiological safety	93

Figure VI–2A and B illustrates the number of personnel trained in these aspects of food irradiation. As shown, China has trained personnel across all areas of food irradiation, with over 60 personnel specifically trained in commercial applications, quality assurance and quality control systems, and in sanitary and phytosanitary treatment. Additionally, Thailand and Myanmar have trained personnel across all areas, while more than 50 personnel have been trained in electron beam and X ray technology.

FIG. VI–2A. Personnel trained in food irradiation by type of training and country.

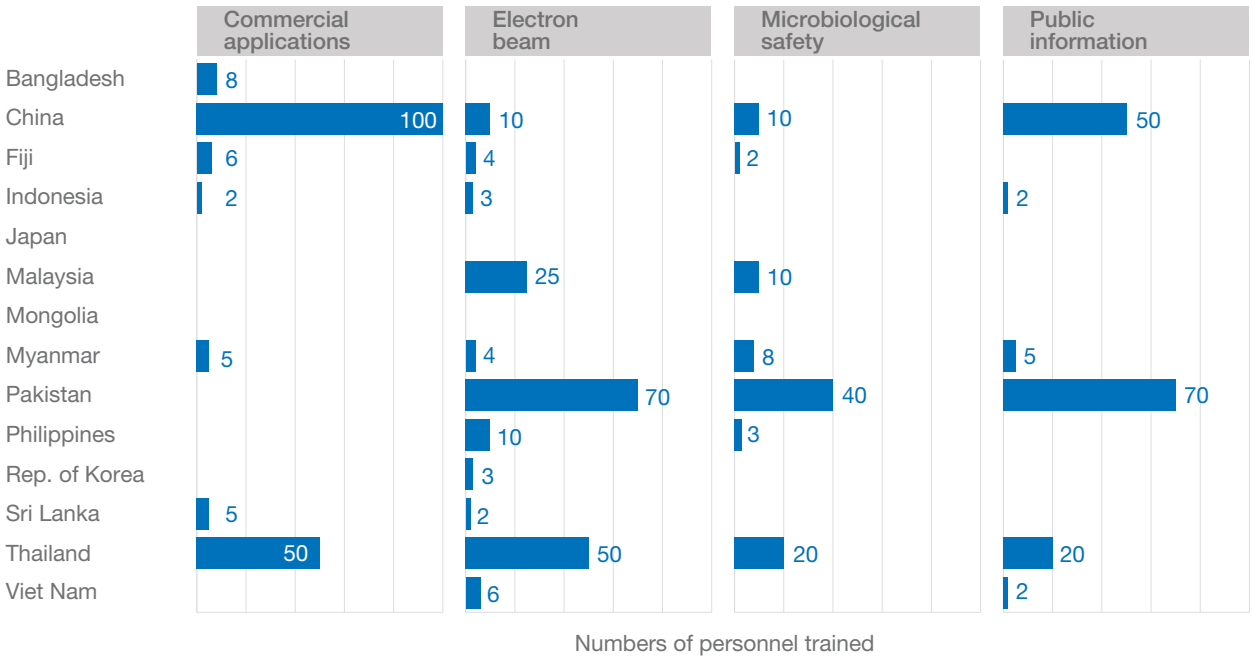
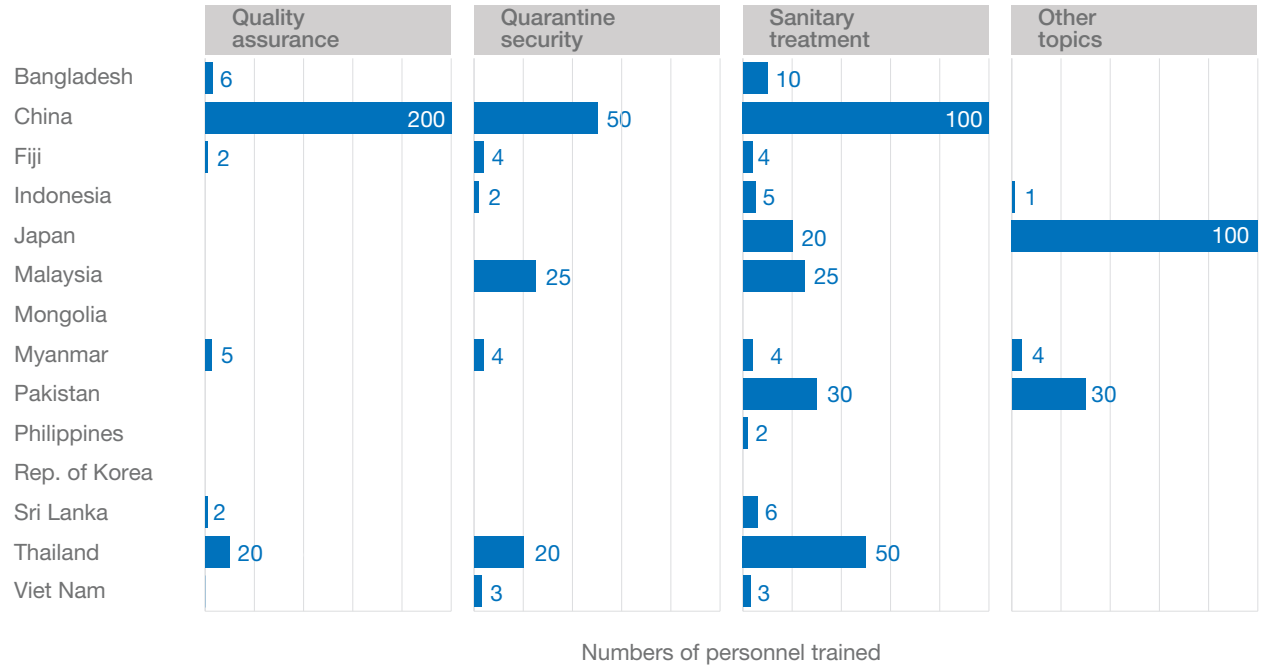


FIG. VI–2B. Personnel trained in food irradiation by type of training and country.



VI–4.2.2. Trained personnel in food origin authentication

According to administrative data provided by the IAEA, the primary RCA FS programme training topics related to food origin authentication are data analysis for food authentication and fundamentals of using nuclear techniques for food authentication.

- **Data analysis for food authentication:** this training teaches personnel to analyze data for verifying food origin, helping detect fraud and ensuring compliance with food labelling and traceability regulations.
- **Fundamentals of using nuclear techniques for food authentication:** this training focuses on nuclear methods, such as isotopic analysis, to authenticate food at a molecular level, ensuring food integrity and compliance with international standards.

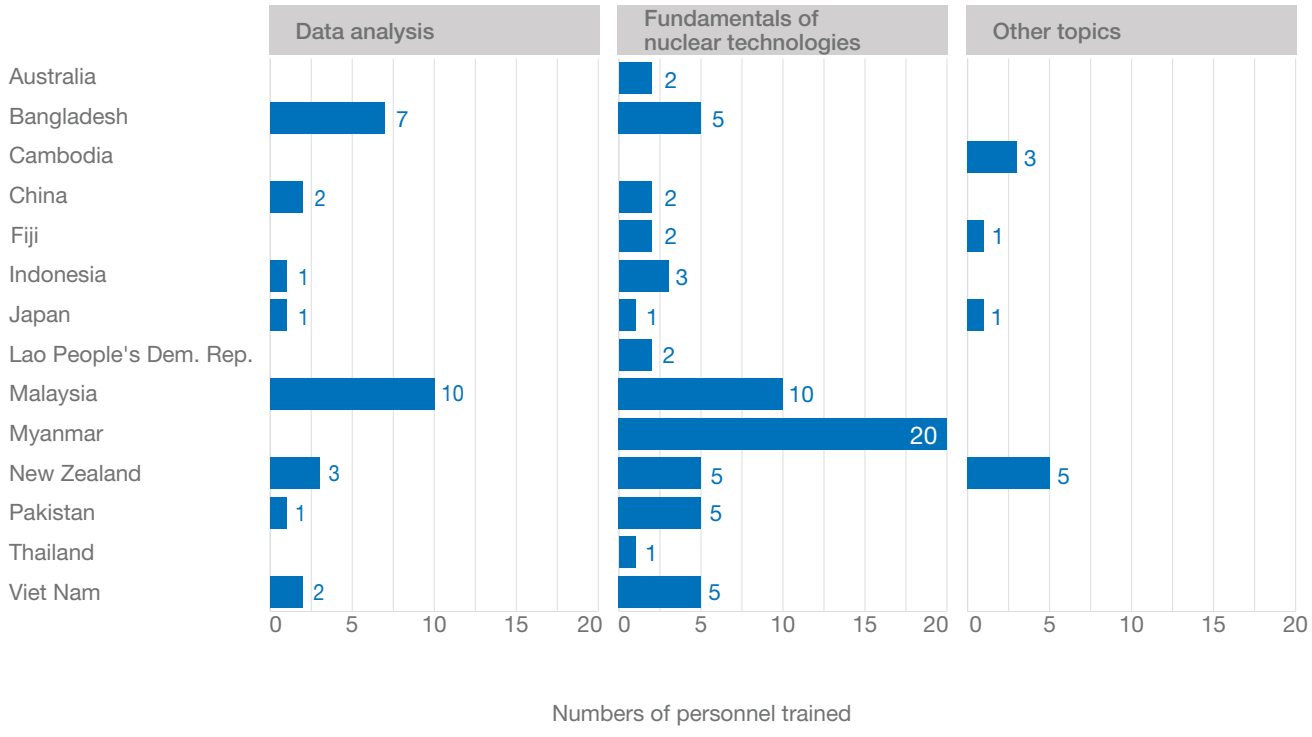
Table VI–4 below shows the total number of nationally trained personnel by the RCA FS programme in each of these topics. As shown, more than 60 personnel have been trained on the fundamentals of using nuclear techniques for food authentication.

Table VI–4. Total number of nationally trained personnel in food origin authentication.

Area	Personnel trained
Fundamentals of using nuclear techniques for food authentication	63
Data analysis for food authentication	27
Other topics	10

Figure VI–3 shows the total number of personnel trained by area and by country. As observed, about ten personnel from Malaysia have been trained in both data analysis for food authentication and fundamentals of using nuclear techniques for food authentication. Additionally, eight countries (Bangladesh, China, Indonesia, Japan, Malaysia, New Zealand, Pakistan and Viet Nam) have trained personnel in both core areas of food authentication.

FIG. VI–3. Personnel trained in food irradiation by type of training and country.



VI–5. Criterion 2: Established infrastructure and improved national research and development for food irradiation and food origin authentication

This section presents an assessment of the extent to which the RCA FS programme has contributed to established infrastructure and improved national R&D capabilities for food irradiation and food origin authentication within participating countries. The assessment focuses on two major areas of RCA support:

Enhanced national R&D capacity The RCA has also bolstered national R&D capabilities, enabling countries to conduct advanced research in food safety and quality. This increased capacity supports:

- **Innovations in food irradiation and authentication:** R&D efforts allow for the development of new techniques and technologies tailored to local needs, leading to more effective and efficient processes.
- **Market and trade trials:** By facilitating trials that ensure food products meet the safety and quality standards required by international markets, these R&D efforts help SPs expand their trade opportunities.
- **Building local expertise:** Enhanced R&D capacity fosters the development of technical expertise and scientific knowledge within each country, empowering local scientists and researchers to address emerging challenges in food safety, quality and traceability.

Establishment of infrastructure The RCA programme has supported the development of essential infrastructure, particularly laboratory facilities for food analysis, irradiation processes and food origin authentication. These facilities are foundational to modern food safety and quality control systems:

- **Food analysis laboratories:** These laboratories play a vital role in testing for contaminants, pathogens and other harmful substances, ensuring that food products meet health and safety standards before they reach consumers.
- **Food irradiation facilities:** Irradiation is a recognized method for reducing spoilage, controlling pests and enhancing the shelf life of foods, all of which are critical for reducing food waste and improving food security.
- **Origin authentication:** Facilities for authenticating the origin of food help protect the integrity of products, especially those with designated origins or geographical indicators. This is important for consumer trust, brand reputation and compliance with international trade regulations.

In summary, this section will focus on how the RCA's support in these areas contributes for advancing food safety and quality assurance frameworks, protecting consumer health and strengthening countries' positions in international trade.

VI–5.1. Ratings and standards of Criterion 2

The standards (levels of performance) for the fulfilment of this criterion are as follows (Table VI–5):

Table VI–5. Ratings and standards of Criterion 2.

Rating	Standard
Excellent (exceeding expectations)	As a result of RCA, there are: ▶ Research outputs and publications on food irradiation **and** food origin authentication (including market and trade trials); **and** ▶ Infrastructure for the provision of national **and** commercial laboratory facilities for food analysis and irradiation **and** food origin authentication
Good (meeting expectations)	As a result of RCA, there are: ▶ Research outputs and publications on food irradiation **and** food origin authentication (including market and trade trials); **and/or** ▶ Infrastructure for the provision of laboratory facilities for food analysis and irradiation **and** food origin authentication
Adequate (meeting bottom-line expectations)	As a result of RCA, there are: ▶ Research outputs and publications on food irradiation **and/or** food origin authentication; **and/or** ▶ Infrastructure for the provision of laboratory facilities for food analysis and irradiation **and/or** food origin authentication
Minor (not meeting expectations)	Standard for adequate not met

Based on data collected from experts in food irradiation and food authentication across the participating countries, **the overall performance rating of the RCA programme was deemed excellent.** This rating adjusts for the perceived level of RCA's contributions to the establishment of infrastructure and the enhancement of national R&D capacity, taking into account the varying baseline capabilities of each country.

VI–5.1.1. Breakdown of ratings by country for Criterion 2

Excellent performance

The RCA programme's performance has been rated as **excellent** in 11 countries.

In particular, **Australia, Bangladesh, China, Indonesia, Malaysia, Myanmar, Thailand and Viet Nam** received an **excellent** rating, as each of these countries met the high standards established in the evaluation rubric.

In **Japan, Lao People's Democratic Republic and Pakistan,** although the evaluation rubric classified the RCA FS programme's performance as **good**, the rating was elevated to **excellent**. This adjustment reflects the countries' perception that the RCA FS programme has made significant contributions to both the development of infrastructure and the enhancement of R&D capabilities.

Good performance

The programme's performance was rated as **good** in four countries: **Fiji, New Zealand, the Philippines and Sri Lanka** all met the standards set for an **adequate** rating. However, due to the high perceived value of the RCA FS programme's contributions in these countries, the performance rating was adjusted to **good**.

Adequate performance

An **adequate** rating was given to **Cambodia and the Republic of Korea,** where the programme met the minimum standards set forth in the evaluation rubric.

Excluded from analysis

Mongolia and Nepal were excluded from this analysis due to limited engagement in the RCA FS programme, which has resulted in minimal contributions in these countries.

VI–5.2. Research outputs and publications developed

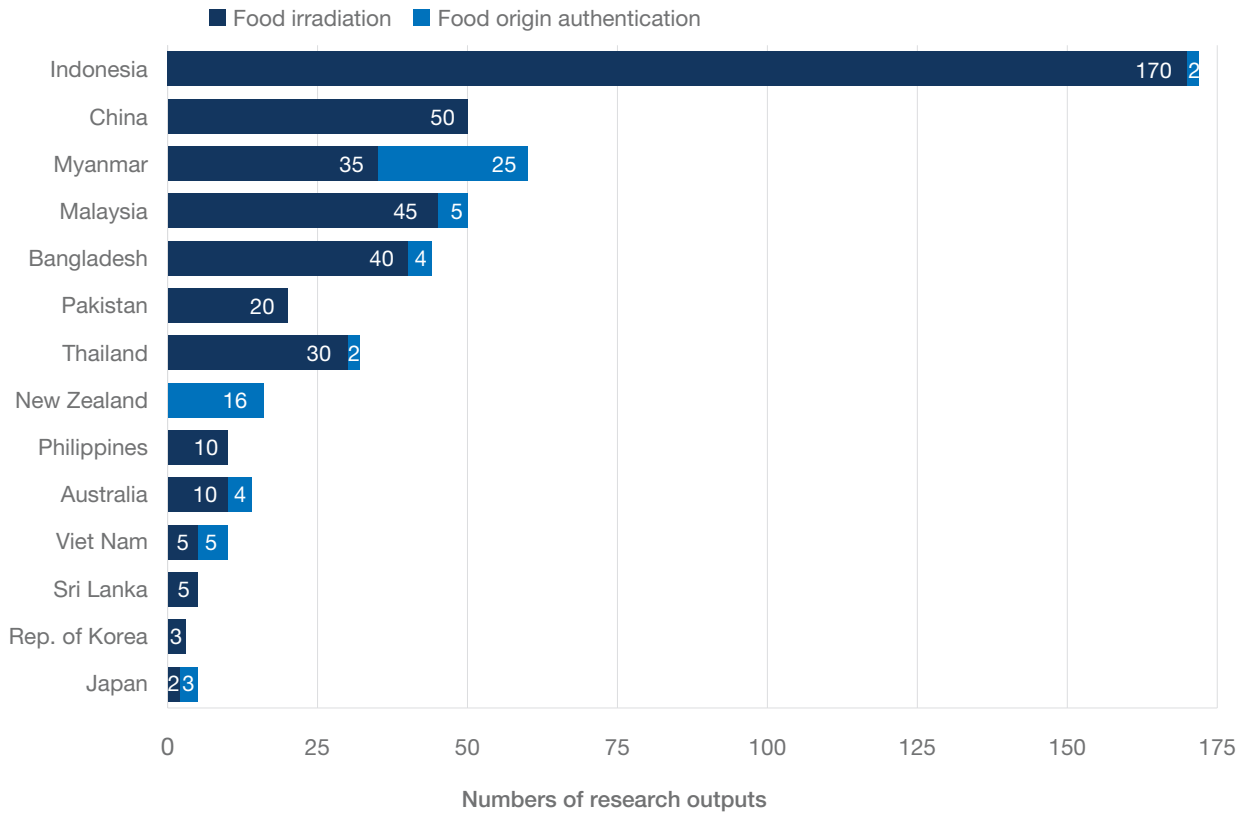
Between 2000 and 2023, the RCA FS programme has contributed to the production of research output and publications in the fields of food irradiation and food origin authentication across participating countries. As a result of the programme's support, **approximately 490 research outputs have been produced.** These publications showcase the programme's influence on advancing scientific knowledge, developing new methodologies and enhancing the technical capabilities of member countries in critical areas of food safety and quality control.

Roughly 85% of the publications generated through RCA FS activities are in the field of food irradiation. This strong focus reflects the programme's emphasis on utilizing food irradiation as a technique to improve food safety, extend shelf life and meet international quality standards. Research in this area includes studies on the effects of irradiation on various food products, optimization of irradiation protocols, safety assessments and investigations into consumer acceptance and regulatory compliance. These publications contribute to a growing body of evidence supporting food irradiation as a viable method for enhancing food safety and preserving food quality.

Indonesia has emerged as the leading contributor to this body of research, producing over 170 publications. This high output underscores Indonesia's active participation and commitment to advancing food safety through research, particularly in food irradiation; **Myanmar** ranks second, with 60 publications in total, divided across both fields (35 publications in food irradiation and 25 in food origin authentication). Myanmar's balanced focus on both food irradiation and food origin authentication indicates a broad research agenda that supports not only food preservation but also traceability and authenticity, which are vital for protecting local products and supporting international trade. Moreover, **China** has produced around 50 publications, contributing valuable insights and data that enhance regional and global understanding of food irradiation and origin authentication technologies.

Figure VI–4 provides a detailed breakdown of the publications by country and research theme, illustrating the programme's overall contributions of each participating country.

FIG. VI–4. Research outputs and publications produced as part of being part of the RCA FS programme.



VI–5.3. Facilities for food analysis, irradiation and authentication

A ‘facility’ in this context refers to infrastructure that provides national and commercial laboratory services for food analysis, food irradiation and food origin authentication. These facilities play a key role in ensuring food safety, quality control and the traceability of food products across international trade.

Across the 19 countries that participated in the survey, there are a total of approximately 410 laboratory facilities dedicated to food analysis, food irradiation and food origin authentication. Of these, 19% are owned and operated by government entities, while 81% are commercial, privately owned facilities.

The majority of these facilities (about 91%) are focused on food irradiation, which is a critical process used for food safety and preservation. Food irradiation involves exposing food to ionizing radiation to eliminate pathogens and extend shelf life. A significant portion of the facilities is thus dedicated to this particular area of food safety.

Among all participating countries, **China stands out with the largest number of facilities, boasting over 322 facilities in total (all focused on food irradiation).** This large number reflects China’s prominent role in the food safety and irradiation sector.

In most countries, the majority of facilities are government owned. However, there are exceptions, such as in Viet Nam, where 65% of the facilities are commercial. This indicates a more privatized approach to food analysis and irradiation in certain countries, with commercial facilities playing a major role in food safety processes.

Table VI–6 offers a detailed breakdown of the number of facilities in each participating country, categorizing them by the type of facility (commercial or government) and their primary field of operation (food origin authentication or food irradiation).

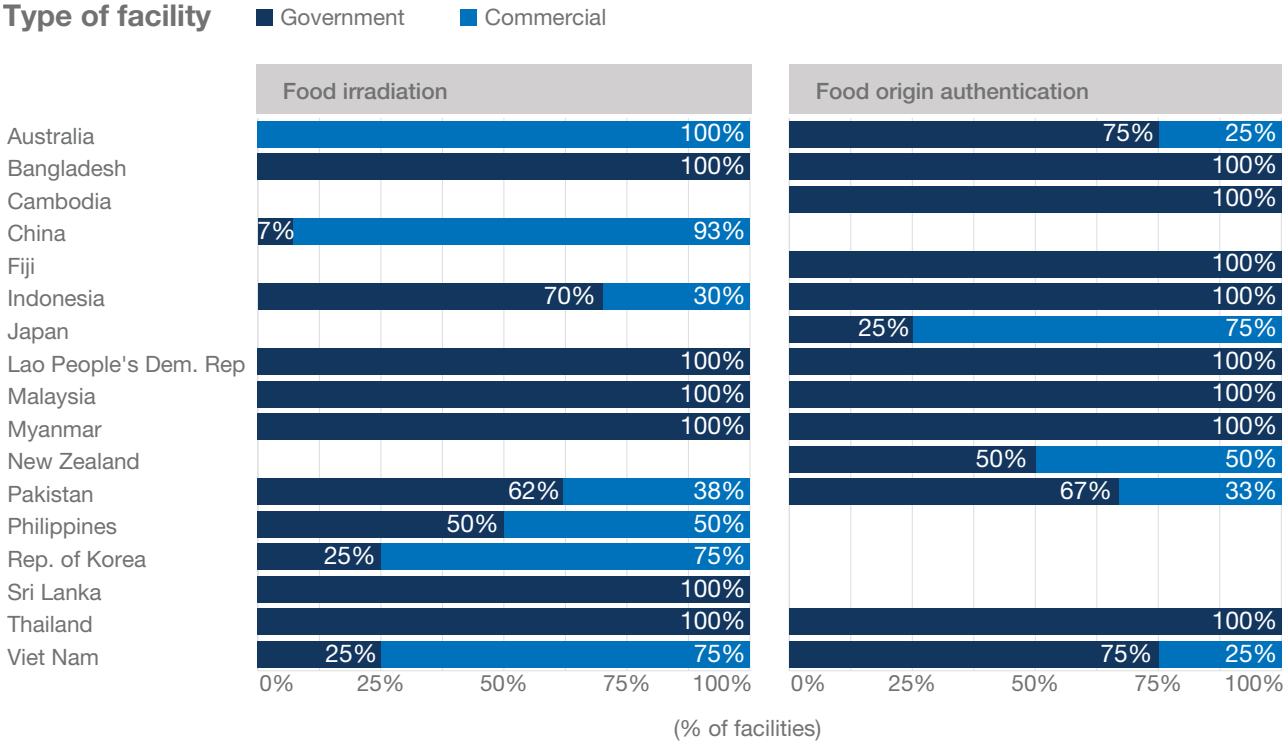
Table VI–6. Total number of facilities by country.

Country	Area	Government	Commercial	Total
Australia	Food irradiation	NA	2	2
Australia	Food origin authentication	3	1	4
Bangladesh	Food irradiation	4	NA	4
Bangladesh	Food origin authentication	5	NA	5
Cambodia	Food origin authentication	3	NA	3
China	Food irradiation	22	300	322
China	Food origin authentication	NA	NA	0
Fiji	Food origin authentication	1	NA	1
Indonesia	Food irradiation	7	3	10
Indonesia	Food origin authentication	2	NA	2
Japan	Food origin authentication	1	3	4
Lao People's Democratic Republic	Food irradiation	1	NA	1
Lao People's Democratic Republic	Food origin authentication	1	NA	1
Malaysia	Food irradiation	1	NA	1
Malaysia	Food origin authentication	2	NA	2
Myanmar	Food irradiation	1	NA	1
Myanmar	Food origin authentication	1	NA	1
New Zealand	Food origin authentication	1	1	2
Pakistan	Food irradiation	5	3	8
Pakistan	Food origin authentication	2	1	3
Philippines	Food irradiation	2	2	4
Republic of Korea	Food irradiation	1	3	4
Sri Lanka	Food irradiation	1	NA	1
Thailand	Food irradiation	3	NA	3
Thailand	Food origin authentication	1	NA	1
Viet Nam	Food irradiation	4	12	16
Viet Nam	Food origin authentication	3	1	4

Figure VI–5 illustrates the proportion of facilities owned by the Government versus those owned by the private sector in each country. In Australia, for example, all facilities dedicated to food irradiation are commercially owned, whereas a majority (75%) of the facilities for food origin authentication are government owned. By contrast, in countries such as Lao People's Democratic Republic,

Malaysia, Myanmar, Sri Lanka and Thailand, all facilities providing these services are government operated. These data highlight the varying structures of facility ownership across different countries.

FIG. VI–5. Proportion of facilities owned by governments and by the private sector.



VI–5.4. Contribution of RCA

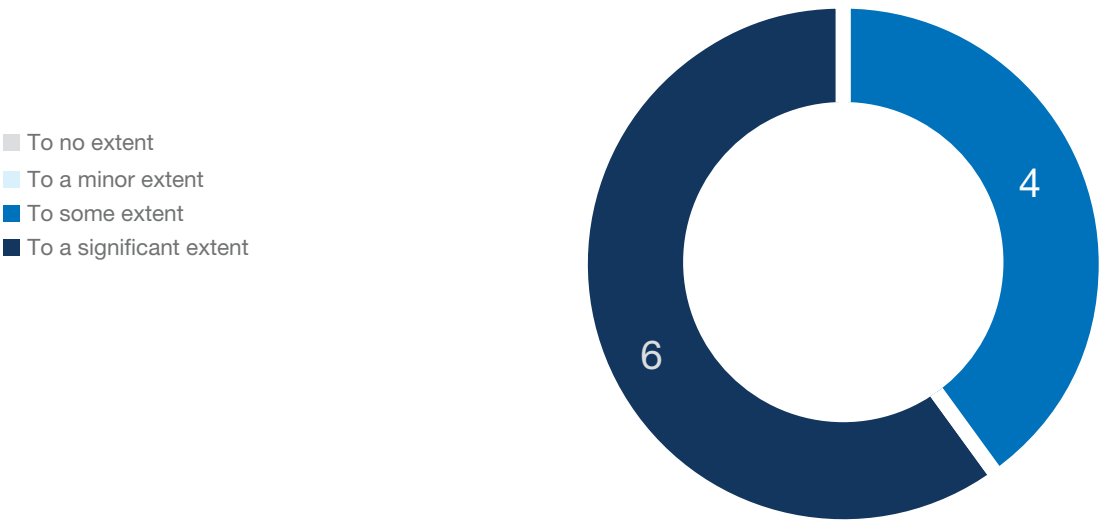
VI–5.4.1. Contribution to the development of research outputs and publications

Figures VI–6 and VI–7 illustrate the perceptions of participant countries regarding the contribution of the RCA FS programme on the development of research outputs and publications in the fields of food irradiation and food origin authentication between 2000 and 2023. Among the 13 countries that reported generating research outputs and publications in **food irradiation** as a result of participating in the RCA FS programme, eight countries considered the programme's contribution to be significant, three countries reported it contributed to some extent, and two countries indicated it contributed to a minor extent. These data provide insight into the varying levels of perceived impact the programme had on advancing research in these areas across participating countries.

FIG. VI–6. RCA's contribution to research outputs on food irradiation.

For the ten countries that reported the RCA FS programme's contribution to the development of research outputs in **food origin authentication**, six considered the support to have contributed to a significant extent, while four felt it contributed to some extent. This indicates a generally positive perception of the programme's impact on research advancements in food origin authentication among these participating countries.

FIG. VI–7. RCA's contribution to research outputs on food origin authentication.



In general, participant countries have a positive perception of the RCA FS programme's contribution to the development of research outputs and publications. The majority of countries that reported advancements in food safety research attributed these developments to the programme, with most indicating that the contribution was significant or moderate. This reflects a generally favourable view of the programme's role in supporting research progress across the participant countries.

VI–5.4.2. Contribution to the development of government facilities

Out of the 12 countries that view the RCA FS programme as contributing to the development of **government facilities in food irradiation** between 2000 and 2023, ten consider the programme to have been a significant or moderate contributor to this development (Fig. VI–8). This suggests that most participant countries recognize the programme's role in advancing government infrastructure for food irradiation.

FIG. VI–8. RCA's contribution to the development of government facilities in food irradiation.

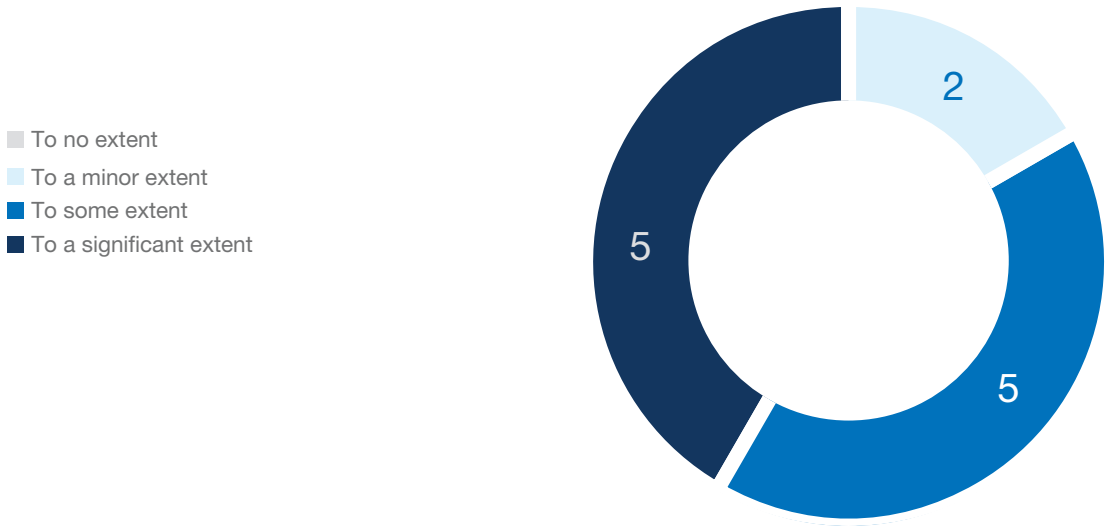
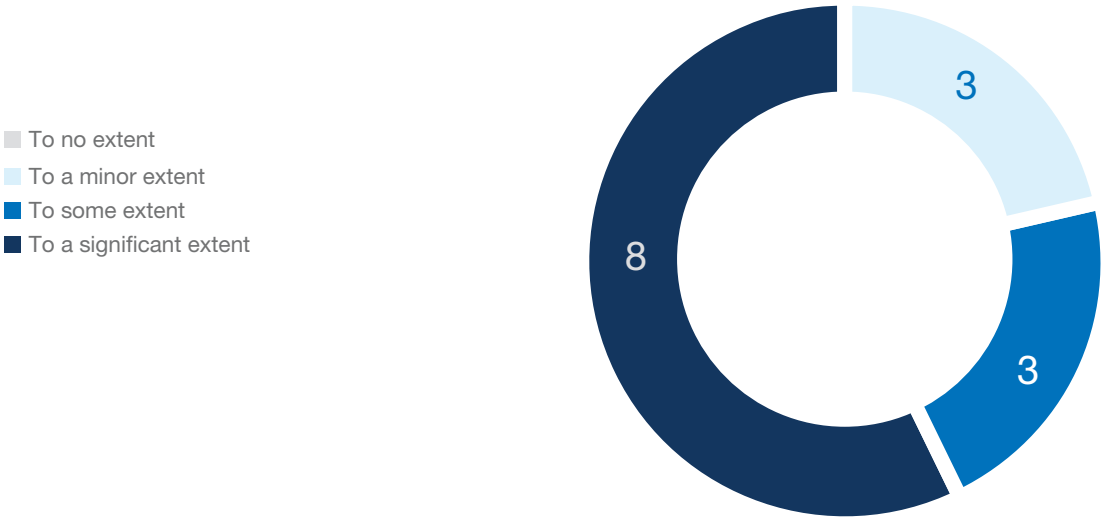


Figure VI–9 presents the perceptions of participating countries on the extent to which the RCA FS programme has contributed to the development of **government facilities in food origin authentication.** As indicated in Fig. VI–9, eight countries consider that the programme has significantly contributed to the development of these facilities between 2000 and 2023, while three countries believe it has contributed to some extent, and another three view the contribution as minor.

FIG. VI–9. RCA's contribution to the development of government facilities in food origin authentication.



VI–6. Criterion 3: Raised awareness and understanding among governments, businesses and the public about the value of food irradiation and food origin authentication

This section presents the results regarding the extent to which the RCA FS programme has contributed to raising awareness and understanding among governments, businesses and the public (consumers) about the value of food irradiation and origin authentication. Specifically, it assesses the extent to which the RCA programme has facilitated:

- Increased **consumer acceptance** of food irradiation and origin authentication, thereby enhancing public trust and confidence in these technologies.
- Improved **business perceptions** of food irradiation and origin authentication, which has led to greater industry adoption and support for these practices.
- Enhanced **government perceptions** of food irradiation and origin authentication, helping to foster stronger regulatory frameworks and policies that support their use in ensuring food safety and quality.

These outcomes underline the RCA programme's effectiveness in raising awareness and fostering positive attitudes towards these critical food safety technologies.

VI–6.1. Ratings and standards of Criterion 3

The standards (levels of performance) for the fulfilment of this criterion are as follows (Table VI–7):

Table VI–7. Ratings and standards of Criterion 3.

Rating	Standard
Excellent (exceeding expectations)	Participation in RCA enables: ▶ An improvement in the Government's **knowledge** about the value of food irradiation and/or food origin authentication; **and** ▶ An improvement in businesses' **knowledge** about the value of food irradiation and/or food origin authentication; **and** ▶ An improvement in consumers' **acceptance** about the value of food irradiation and/or food origin authentication
Good (meeting expectations)	Participation in RCA enables: ▶ An improvement in the Government's **knowledge** about the value of food irradiation and/or food origin authentication; **and** ▶ An improvement in businesses' **knowledge** about the value of food irradiation and/or food origin authentication; **and** ▶ An improvement in consumers' **knowledge** about the value of food irradiation and/or food origin authentication
Adequate (meeting bottom-line expectations)	Participation in RCA enables: ▶ An improvement in the Government's **knowledge** about the value of food irradiation and/or food origin authentication; **and/or** ▶ An improvement in businesses' **knowledge** about the value of food irradiation and/or food origin authentication
Minor (not meeting expectations)	Standard for adequate not met

Based on the data provided by the GPs, **the overall rating of the RCA FS programme's contribution to raising awareness and understanding among governments, businesses and the public about the value of food irradiation and origin authentication is excellent.**

VI–6.1.1. Breakdown of ratings by country for Criterion 3

The programme's performance across participating countries is rated as follows:

→ **Excellent:** Seven countries (**China, Fiji, Malaysia, Myanmar, Pakistan, Sri Lanka and Thailand**) reported that the programme exceeded expectations, showing marked improvements in government and business knowledge as well as consumer acceptance of food irradiation and origin authentication.

- **Good:** Seven countries (**Australia, Bangladesh, Indonesia, Japan, Lao People's Democratic Republic, Mongolia and Viet Nam**) indicated that the programme met expectations, with increased knowledge among governments, businesses and consumers.
- **Adequate:** Four countries (**Cambodia, Nepal, New Zealand and the Philippines**) noted that the programme met basic expectations, contributing to improvements in government or business knowledge.
- **Minor:** The **Republic of Korea** reported that the programme did not meet the minimum standards for raising awareness and understanding.

These results reflect the programme's varying levels of impact across different regions in supporting knowledge and acceptance of food irradiation and origin authentication.

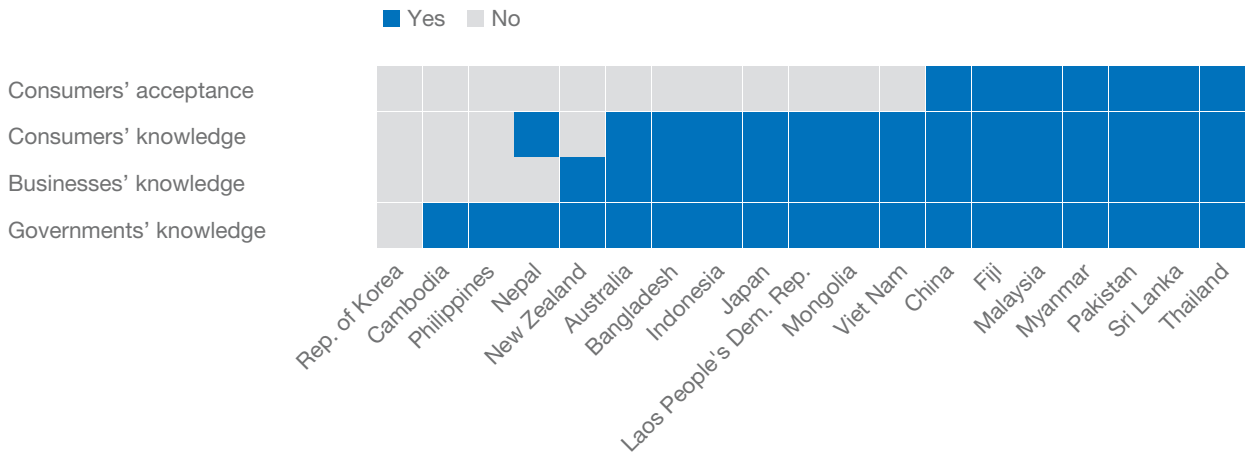
VI–6.1.2. Raised awareness across sectors

The GPs were asked to assess whether, as a result of their participation in the RCA FS programme, there has been an improvement in the knowledge of **governments, businesses and consumers** about the use of nuclear techniques for food origin authentication and food irradiation for both domestic consumption and export. Additionally, GPs were asked to evaluate the extent to which **consumers understand the difference between "irradiated" and "radioactive" food,** as well as their level of comfort with consuming irradiated food.

Figure VI–10 presents the programme's contribution across these dimensions. As shown in Fig. VI–10, in countries such as **China, Fiji, Malaysia, Myanmar, Pakistan, Sri Lanka and Thailand,** participation in the RCA FS programme has led to improvements in knowledge across governments, businesses and consumers. Furthermore, in these countries, there is a perception that the programme has successfully contributed to consumers' understanding of the difference between irradiated and radioactive food, increasing their comfort with consuming irradiated products.

In other countries, including **Australia, Bangladesh, Indonesia, Japan, Lao People's Democratic Republic, Mongolia and Viet Nam,** while knowledge among governments, businesses and consumers has also increased, there remains a perception that additional efforts are needed to improve consumer confidence in the safety of irradiated food. This suggests that although progress has been made, further awareness initiatives may be beneficial in these regions to enhance consumer comfort with irradiated food.

FIG. VI–10. RCA's contribution to raise awareness and understanding about the value of food irradiation and food origin authentication.



VI–7. Criterion 4: Developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication

This section presents the findings on the extent to which the RCA FS programme has contributed to the development and adoption of harmonized standards, guidelines and protocols for food irradiation and origin authentication. Specifically, it examines the programme's contribution on enabling:

- Regulations and policies supporting food irradiation,
- Guidelines and protocols for the use of origin authentication technology.

The findings are organized around four primary questions related to the programme's outcomes:

1. **Contribution to new or revised guidelines and protocols for origin authentication**
   The analysis explores whether the RCA FS programme has facilitated the development of new guidelines or revisions to existing protocols specifically tailored to origin authentication technology. This aspect assesses if new best practices or updated standards have been introduced, providing a **standardized** approach across different regions.

2. **Impact on regulations supporting food irradiation**
   This section reviews whether the programme has influenced the creation or modification of regulatory frameworks supporting food irradiation. It evaluates

how the programme could have contributed to aligning national regulations with international standards or improving consistency in food irradiation policies.

3. **Influence on policy decisions and interventions related to food irradiation**
   This area examines if the programme has encouraged policy level decisions or interventions supporting food irradiation. Such contributions could include fostering governmental or organizational commitments to uphold food safety and extend shelf life using food irradiation technologies.

4. **Absence of measurable outcomes or limited impact**
   The analysis also considers if the RCA FS programme has not led to any notable advancements in the specified areas. This scenario implies either an absence of new or revised standards, regulations or policies directly linked to the programme's activities.

Overall, these findings aim to determine the RCA FS programme's effectiveness in advancing harmonized practices in food irradiation and origin authentication and to identify any areas where further development may be needed.

VI–7.1. Ratings and standards of Criterion 4

The standards (levels of performance) for the fulfilment of this criterion are as follows (Table VI–8):

Table VI–8. Ratings and standards of Criterion 4.

Rating	Standard
Excellent (exceeding expectations)	Participation in RCA enables a **significant** increase in: ▶ New regulations or changes to existing regulations and policies that support food irradiation ▶ Policy decisions and interventions related to food irradiation ▶ New guidelines and protocols or changes to guidelines and protocols for the use of origin authentication technology
Good (meeting expectations)	Participation in RCA enables **some** increase in: ▶ New regulations or changes to existing regulations that support food irradiation ▶ Policy decisions and interventions related to food irradiation ▶ New guidelines and protocols or changes to guidelines and protocols for the use of origin authentication technology
Adequate (meeting bottom-line expectations)	Participation in RCA enables **any** increase in: ▶ New regulations or changes to existing regulations that support food irradiation ▶ Policy decisions and interventions related to food irradiation ▶ New guidelines and protocols or changes to guidelines and protocols for the use of origin authentication technology
Minor (not meeting expectations)	Standard for adequate not met

Based on the analysis conducted on the data provided by the GPs, **the RCA FS programme's contribution on developing and adopting harmonized standards, guidelines and protocols for food irradiation and origin authentication has been rated as good overall,** indicating it met expectations in supporting regulatory and policy changes, as well as in enhancing guidelines and protocols related to origin authentication technology. This rating reflects varying levels of effectiveness across participant countries, recognizing that baseline levels of development and the programme's specific contributions vary by country.

VI–7.1.1. Breakdown of ratings by country for Criterion 4

Excellent: Six countries demonstrated a significant increase in relevant standards and policies, exceeding expectations.

- **Countries:** China, Malaysia, Myanmar, New Zealand, Sri Lanka and Thailand
- **Achievements:** In these countries, participation in the RCA FS programme contributed to substantial advancements, including the establishment of new regulations or substantial revisions to existing policies supporting food irradiation. Additionally, some of these countries saw meaningful updates or new guidelines and protocols for origin authentication.

Good: Six countries showed some positive changes meeting expectations.

- **Countries:** Bangladesh, Fiji, Indonesia, Japan, Pakistan and Viet Nam
- **Achievements:** In these countries, the programme facilitated some progress, with some development in regulations, policies or guidelines related to food irradiation and origin authentication, though not to the extent of needed for an excellent rating.

Minor Advancements: In seven countries, the RCA FS programme did not yield significant progress.

- **Countries:** Australia, Cambodia, Lao People's Democratic Republic, Mongolia, Nepal, the Philippines and the Republic of Korea
- **Findings:** For these countries, the programme did not contribute notable advancements toward the development or adoption of regulations, policies or protocols for food irradiation or origin authentication.

The varied ratings reflect the differing baseline levels of each country's regulatory and policy environment in food irradiation and origin authentication. The RCA FS programme has made substantial contributions in some countries, while others may need additional support or tailored interventions to realize similar progress.

VI–7.2. Contribution to developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication

Figure VI–11 illustrates how participation in the RCA FS programme from 2000 to 2023 has influenced the establishment and adoption of harmonized standards, guidelines and protocols related to food irradiation and origin authentication across countries. The programme's contributions are categorized into three key dimensions:

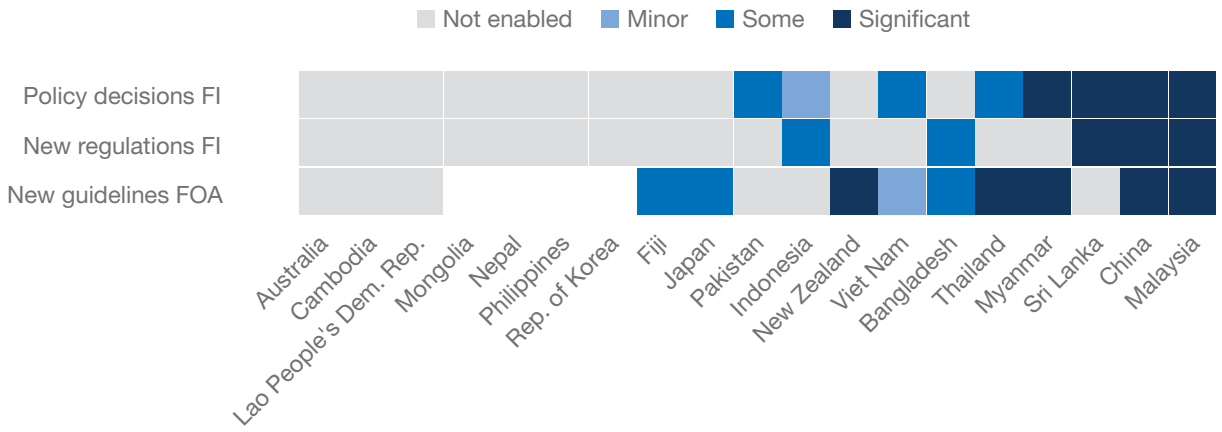
1. **New guidelines and protocols** or updates in existing guidelines for using origin authentication technology;
2. **New regulations** or revisions to support food irradiation;
3. **Policy decisions and interventions** concerning food irradiation.

Figure VI–11 shows the following results:

- **China and Malaysia:** These countries have seen significant contributions from the programme across all three dimensions, highlighting the RCA FS programme's success in fostering a comprehensive approach to food safety and regulation in these regions.
- **Sri Lanka:** The programme has notably influenced Sri Lanka in developing policies related to food origin authentication and establishing new regulations on food irradiation.
- **Fiji, Japan and Bangladesh:** The programme has moderately impacted these countries, specifically by aiding in the development of new guidelines and protocols for origin authentication technology.
- **Australia, Cambodia, Lao People's Democratic Republic, Mongolia, Nepal, the Philippines and the Republic of Korea:** These countries reported no significant advancements across any of the dimensions, indicating limited or no impact from the programme.
- **Blank spaces in the chart:** The blank spaces indicate areas where data were either not collected or unavailable. For instance, New Zealand did not participate in the food irradiation survey, and Mongolia did not engage in the food origin authentication survey. This absence of data signifies either non-participation in specific surveys or gaps in data collection for particular dimensions.

In summary, the RCA FS programme has had varying levels of impact across participating countries, with some, such as China and Malaysia, showing substantial progress across all three dimensions, while others reported no advancements. Missing data in some areas reflect incomplete responses or non-participation in certain surveys.

FIG. VI–11. RCA's contribution to developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication.



VI–8. Criterion 5: Enhanced and effective application of irradiation and nuclear technologies, including commercial treatment capacities for an expanding range of food products

This section provides an analysis of how the RCA FS programme has contributed to **enhanced and effective application of irradiation and nuclear technologies, including commercial treatment capacities for an expanding range of food products.** The criterion specifically aims to measure the programme's effectiveness in supporting the adoption and integration of these technologies into food systems in participating countries.

In this section, the RCA FS programme has been evaluated for its role in advancing two primary objectives related to the effective application of irradiation and nuclear technologies for an expanding range of products:

1. **Expanding the use of irradiation across a broader range of food products**
   This objective focuses on whether the RCA FS programme has enabled countries to extend irradiation technology to more food products, thus broadening its scope beyond traditional applications. Irradiation is widely recognized for its potential to enhance food safety by reducing pathogens and extending shelf life, which has implications for food security and trade [VI–1]. Expanding the range of irradiated products, therefore, could support countries in meeting food safety standards, reducing post-harvest losses and enhancing the economic value of certain foods [VI–2].

2. Commercial use of food authentication technologies

This objective assesses the RCA FS programme's contribution on the commercial use of food authentication (origin authentication) technologies. Food authentication plays a crucial role in confirming product origins, quality and authenticity, which is increasingly essential in globalized food markets where consumers demand transparency and assurance about food sources. Enhanced capacity for origin authentication can help countries combat food fraud, strengthen export credibility and align with international trade standards [VI–3].

VI–8.1. Ratings and standards of Criterion 5

The standards (levels of performance) for the fulfilment of this criterion are as follows (Table VI–9):

Table VI–9. Ratings and standards of Criterion 5.

Rating	Standard
Excellent (exceeding expectations)	RCA enables: ▶ An expansion of the use of irradiation to a wider range of food products; **and** ▶ An expansion of the commercial use of food irradiation **and** food origin authentication
Good (meeting expectations)	RCA enables: ▶ An expansion of the use of irradiation to a wider range of food products; **and/or** ▶ An expansion of the commercial use of food irradiation **and/or** food origin authentication
Adequate (meeting bottom-line expectations)	RCA enables: ▶ An expansion of the use of irradiation to a wider range of food products
Minor (not meeting expectations)	Standard for adequate not met

Based on the analysis, **the RCA FS programme has achieved a good rating for Criterion 5.** This indicates that the programme has effectively supported the use of irradiation and nuclear technologies for food safety and origin authentication in a significant number of participating countries. While eight countries received an excellent rating with broad commercial application, other countries demonstrated a good or an adequate rating, expanding irradiation use for selecting food products or within specific sectors. However, several countries have yet to implement these technologies, highlighting areas for future support and development.

VI–8.1.1. Breakdown of ratings by country for Criterion 4

- **Excellent performance:** The programme performed excellently in eight countries —**Australia, Bangladesh, Indonesia, Malaysia, Myanmar, Pakistan, Thailand and Viet Nam.** In these countries, at least one type of food is irradiated, and there is commercial use for both food irradiation and food origin authentication. This demonstrates a comprehensive integration of irradiation technologies into their food systems.
- **Good performance:** The programme achieved a good rating in **China and Japan.** In these countries, food is irradiated for both food irradiation and food origin authentication. However, the irradiation is either not used for commercial purposes or is only used commercially in one area but not the other, indicating a partial but significant adoption of the technology.
- **Adequate performance:** The programme was rated as adequate in **Cambodia, the Philippines and the Republic of Korea.** In these countries, at least one type of food is irradiated either for food irradiation or food authentication, meeting the basic level of the criterion but not fully expanding into commercial applications.
- **Minor performance:** Countries that reported no use of food irradiation include **Fiji, Lao People's Democratic Republic, Mongolia, Nepal, New Zealand and Sri Lanka.** These countries have not yet adopted irradiation technologies, indicating that the programme's impact in these countries is minimal or non-existent regarding this criterion.

This detailed analysis highlights the varying levels of success across different countries, reflecting both the achievements and areas for improvement within the RCA FS programme's efforts to enhance and effectively apply irradiation and nuclear technologies in food systems.

VI–8.2. Application of irradiation technologies

The RCA FS programme surveyed participant countries to identify the types of food irradiated or subjected to nuclear techniques for origin authentication. Participants were asked to specify which foods were irradiated and, among those, which were treated for commercial purposes, whether for domestic consumption or export. Figure VI–12 displays the status of food irradiation by country, with each food type marked as either **irradiated for commercial purposes** (dark blue), **irradiated for research only** (light blue) or **not irradiated** (light grey).

The data reveal that **herbs and spices, vegetables and fresh fruits** are the most commonly irradiated foods across the region. While some foods, such as wheat and pork, are irradiated only in Myanmar and Viet Nam, these are not yet irradiated commercially. Foods most frequently irradiated for commercial purposes include herbs and spices, vegetables, fresh fruits and seafood.

Countries with the most extensive application of irradiation technologies are **Myanmar**, which irradiates eight food types, followed by **Viet Nam, Thailand and Indonesia,** each irradiating seven food types. This distribution highlights both the variety of irradiated foods and the varying levels of commercial application across participant countries.

FIG. VI–12. Types of food that are irradiated and irradiated for commercial purposes (food irradiation) by country.

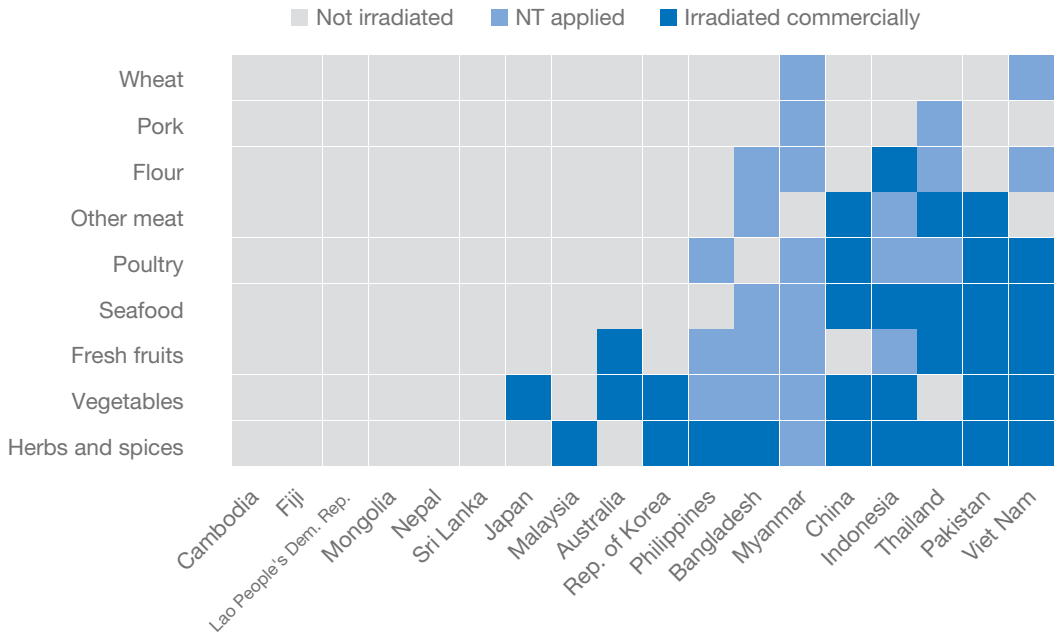


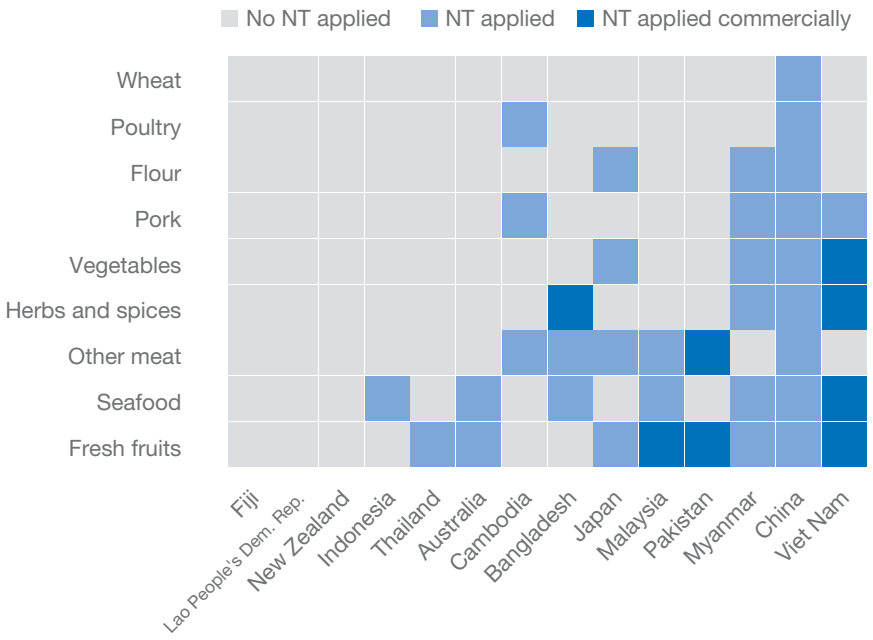
Figure VI–13 illustrates the types of food subjected to nuclear techniques for origin authentication across participating countries. As shown in the chart, the food items most commonly analyzed for origin authentication include **fresh fruits, seafood and various types of meat.** These food categories are prioritized due to their significance in international trade and the increasing demand for verified food sources [VI–3].

Among all the food items analyzed, only **vegetables, herbs and spices, seafood and fresh fruits** are tested for origin authentication on a commercial scale. This indicates that while the technology is gaining traction in some countries, its application remains more limited for certain food types. The countries that have adopted nuclear techniques for the widest range of food types include **China**, which applies these methods to all food categories listed, followed by **Myanmar** (six food types), **Viet Nam** (five food types), and **Japan** (four food types). These countries have made significant strides in utilizing nuclear technology for food traceability and ensuring the integrity of food products for both domestic consumption and international trade.

Fiji, Lao People's Democratic Republic and New Zealand reported that nuclear techniques for food origin authentication are not yet applied in their countries, indicating that these nations have not yet adopted this technology on

a broader scale. This highlights areas where further development and support are needed to integrate these advanced techniques into the food systems of these countries.

FIG. VI–13. Types of food that are irradiated and irradiated for commercial purposes (food origin authentication) by country. Note: NT stands for nuclear techniques used for food origin authentication.



VI–8.3. Contribution of the RCA FS programme to enabling food irradiation

To assess the role of the RCA FS programme in promoting the use of irradiation for food, experts of the participating countries were asked:

1. *In your opinion, to what extent did participation in the RCA FS programme enable the irradiation of food for research and development purposes?*
2. *In your opinion, to what extent did participation in the RCA FS programme enable the export of irradiated products?*
3. *In your opinion, to what extent did participation in the RCA FS programme enable the domestic consumption of irradiated products?*

These questions were designed to evaluate the perceived impact of the RCA FS programme on various aspects of food irradiation—specifically research and development, domestic consumption and export capabilities.

The analysis focused on understanding how the RCA FS programme influenced food irradiation practices across different dimensions in countries actively conducting irradiation. Responses were categorized by the degree of contribution the programme was perceived to have made in each area, ranging from significant, some, minor or none; the findings are listed below.

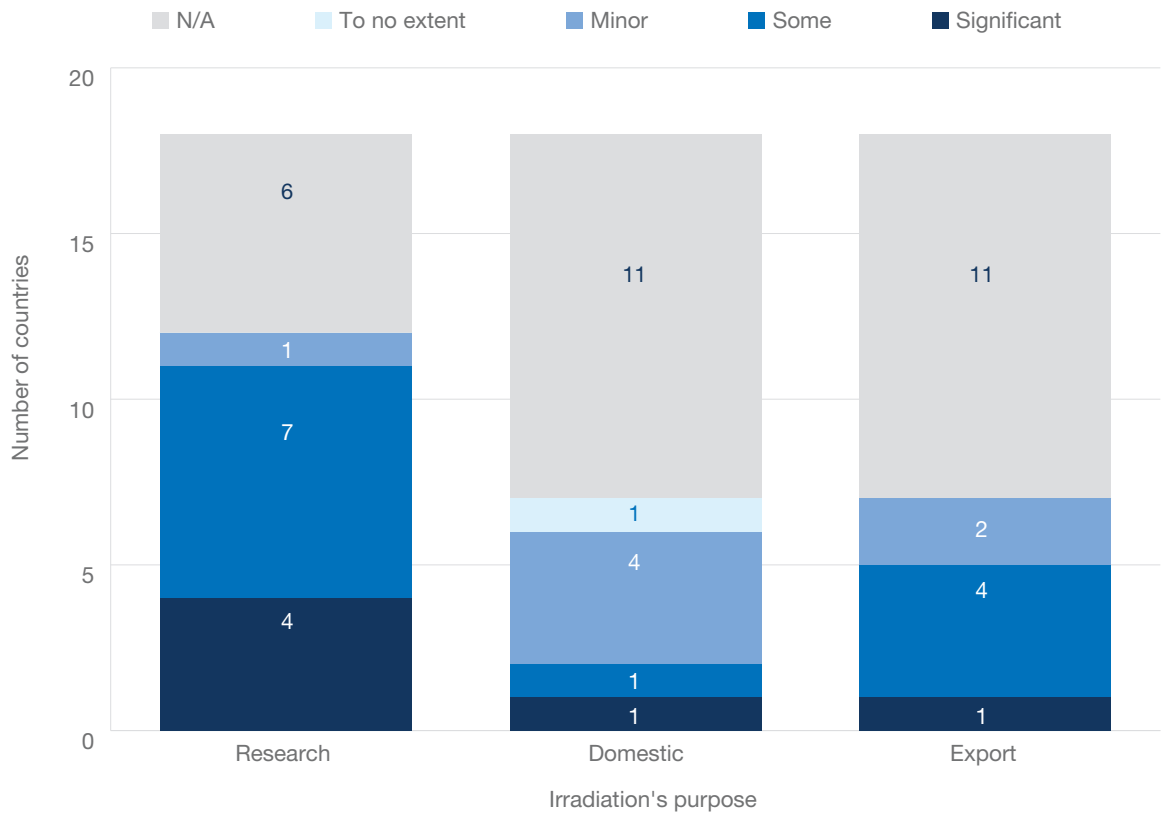
1. **R&D purposes:** A majority of participating countries found the RCA FS programme valuable in advancing food irradiation for R&D purposes, with over 90% attributing at least some degree of support to the programme. Out of 12 countries conducting food irradiation for R&D, perceptions of the RCA FS programme's impact were varied:
   - → **Significant contribution:** Four countries reported that the programme played a significant role in enabling food irradiation for research.
   - → **Some contribution:** Seven countries noted that the programme played some role in supporting their irradiation efforts for R&D.
   - → **Minor contribution:** One country felt the programme's role was minor in this area.

2. **Domestic consumption:** While the programme has supported some efforts for domestic use of irradiated food, most countries view its contribution as limited in this area. This could indicate that domestic policy or market conditions play a larger role than RCA FS programme support in enabling local consumption. Among the seven countries conducting food irradiation for domestic markets, the RCA FS programme's contribution was less pronounced:
   - → **Significant contribution:** One country acknowledged a significant role of the programme.
   - → **Some contribution:** One country recognized some support from the programme.
   - → **Minor contribution:** Four countries indicated a minor role.
   - → **No contribution:** One country reported that the programme had no impact.

3. **Export of irradiated products:** In terms of enabling export, the programme's impact was moderate, with most countries recognizing some level of support. However, a significant role was noted only by one country, suggesting room for further enhancement in facilitating international trade. For export purposes, among seven countries with irradiation capabilities:
   - → **Significant contribution:** One country credited the RCA FS programme with significant support.
   - → **Some contribution:** Four countries perceived the programme as providing some support.
   - → **Minor contribution:** Two countries viewed the programme's role as minor.

The survey indicates that the RCA FS programme has been relatively more effective in enabling irradiation for research and development purposes than for domestic or export applications (Fig. VI–14). While the programme plays a role across all three dimensions, its influence on domestic consumption and export of irradiated food is perceived as more limited. This feedback can guide potential improvements in programme focus areas, particularly in expanding support for domestic and export applications where demand exists.

FIG. VI–14. Perceived contribution of RCA FS programme to food irradiation by application area.



VI–9. Criterion 7: Health and environmental benefits[2]

This section examines the perceived impact of the RCA FS programme on health and environmental benefits in participating countries. Specifically, it explores expert assessments on how the programme has supported improvements in key areas, including:

- **Reductions in morbidity and mortality** due to decreased incidence of food borne illnesses;
- **Decreased chemical use in post-harvest processes,** which contributes to lower levels of soil and water contamination;
- **Enhanced transparency in the agricultural-food supply chain,** promoting greater accountability and safety from production to consumption.

Through survey responses, this section provides insights into the extent to which the RCA FS programme is believed to advance these objectives, as viewed by professionals involved in food safety and environmental health across member countries.

[2] Criterion 6 is comprehensively addressed in Annex VII.

VI–9.1. Ratings and standards of Criterion 7

The standards (levels of performance) for the fulfilment of this criterion are as follows (Table VI–10):

Table VI–10. Ratings and standards of Criterion 7.

Rating	Standard
Excellent (exceeding expectations)	Participation in the RCA enables **significant:** ▶ Reduction in morbidity and mortality from foodborne illnesses ▶ Reduction in chemical use post-harvest, thereby lowering soil and water contamination ▶ Improvement in transparency in the agricultural-food supply chain
Good (meeting expectations)	Participation in the RCA enables **some:** ▶ Reduction in morbidity and mortality from foodborne illnesses ▶ Reduction in chemical use post-harvest, thereby lowering soil and water contamination ▶ Improvement in transparency in the agricultural-food supply chain
Adequate (meeting bottom-line expectations)	Participation in the RCA enables **any:** ▶ Reduction in morbidity and mortality from foodborne illnesses ▶ Reduction in chemical use post-harvest, thereby lowering soil and water contamination ▶ Improvement in transparency in the agricultural-food supply chain
Minor (not meeting expectations)	Standard for adequate not met

Based on expert perceptions, the overall rating for Criterion 7 is **good**, indicating that the RCA FS programme is generally perceived as effective in supporting health and environmental benefits.

VI–9.1.1. Breakdown of ratings by country for Criterion 7

- **Excellent:** Five countries—**Bangladesh, China, Fiji, Myanmar and the Philippines**—received an excellent rating, with experts perceiving that the programme enabled significant benefits in reducing foodborne illness rates, minimizing chemical use post-harvest or increasing agricultural-food supply chain transparency.
- **Good:** Eight countries—**Australia, Japan, Lao People's Democratic Republic, Malaysia, New Zealand, Pakistan, Sri Lanka and Thailand**—received a good rating, as experts reported that the programme contributed to some improvements in the evaluated areas, though not to the same significant extent as those rated excellent.
- **Adequate:** Three countries—**Indonesia, Mongolia and Viet Nam**—received an adequate rating, indicating that the programme facilitated at least one of the targeted health or environmental benefits to a basic level.
- **Minor:** Three countries—**Cambodia, Nepal and the Republic of Korea**—were rated minor, with experts perceiving that the programme did not play a role on any of these dimensions.

These findings underscore the variability in the programme's perceived impact across countries, with certain countries experiencing substantial benefits while others seeing more limited contributions. The insights gathered will guide further enhancement of the RCA FS programme to support broader and deeper health and environmental improvements across the region.

VI–9.2. Contribution of the RCA FS programme on health and environmental outcomes: experts' perceptions

To assess experts' perceptions of the RCA FS programme's contribution on health and environmental benefits across participating countries, three key dimensions were explored. Experts were asked to evaluate the programme's contribution to (1) reducing chemical use post-harvest to minimize soil and water contamination, (2) lowering morbidity and mortality rates linked to foodborne illnesses and (3) improving transparency within the agricultural-food supply chain. These dimensions were evaluated over the period from 2000 to 2023 to gauge the programme's perceived long term impact.

1. **Reduction in chemical use post-harvest:** Responses indicate a mixed perception of the programme's role in reducing chemical usage in post-harvest processes. These findings suggest that while some countries recognize the RCA FS programme as supportive in lowering chemical usage, some see limited or no impact, indicating possible variation in programme implementation or national adoption rates.

2. **Reduction in morbidity and mortality from foodborne illnesses:** Overall, a substantial portion of respondents acknowledged at least some role of the programme in reducing health risks from foodborne pathogens.

3. **Improvement in transparency within the agricultural-food supply chain:** In terms of enhancing transparency across the food supply chain, the results show that, while some positive effects were perceived, the programme's contribution to transparency improvements was relatively modest. This could reflect varying degrees of infrastructure, policy alignment or transparency practices across countries.

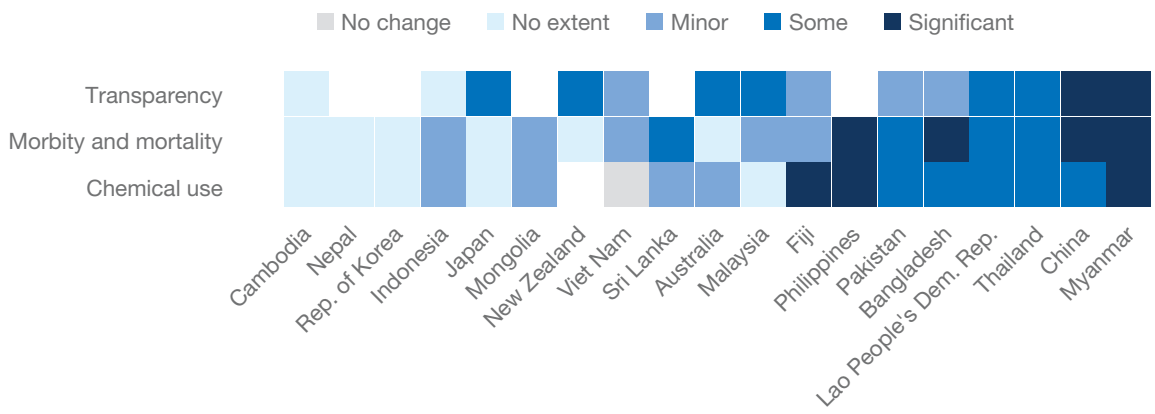
In summary, the RCA FS programme is seen as having a generally positive but varied impact on health and environmental goals across its member countries. The most substantial perceived impact was in reducing foodborne illnesses, with moderate results in chemical use reduction and transparency. This variability highlights areas for potential improvement, particularly in establishing more consistent practices or resources to support transparency and chemical reduction efforts.

Figure VI–15 displays expert perceptions of the RCA FS programme's contribution on three key areas: reduction in chemical use post-harvest, reduction in morbidity and mortality from foodborne illnesses, and improvement in transparency within the agricultural-food supply chain. The results are shown across different levels of perceived contribution:

- **Dark blue** represents a **significant impact,** where experts felt the programme made substantial contributions.
- **Medium blue** indicates **some impact,** signifying a moderate role of the programme.
- **Light blue** shows **minor or no impact,** suggesting limited or minimal influence.
- **Grey** represents **no extent of impact,** where experts saw no contribution from the programme.

Figure VI–15 helps clarify where the RCA FS programme has been most effective according to experts and where potential gaps or areas for improvement could exist.

FIG. VI–15. Expert perceptions of the RCA FS programme's contribution on health and environmental benefits (2000–2023).



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Annex VII: Economic analysis

VII–1. Summary and discussion

An economic framework was developed to analyze economic impacts *enabled by* the Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA) food safety activities being evaluated, for comparison with costs of those activities. The objective is to assess whether the RCA activities generated enough benefits to justify the associated costs.

The benefits enabled by the RCA activities being evaluated come from improved food safety outcomes, compared to what would have occurred in the absence of the RCA activities. Due to the indirect nature of the impacts of RCA activities on food safety and corresponding economic outcomes, and substantial uncertainties about the size of these impacts, it is not possible to precisely calculate the value of benefits of the RCA activities being evaluated. Instead, the economic analysis aims to assess how likely it is that the value of benefits enabled by the RCA activities exceeded the costs of those activities.

The economic analysis focuses on food safety outcomes that are relevant to the RCA activities being evaluated. These activities are related to food irradiation and the use of nuclear techniques for origin authentication. In practice, only impacts of food irradiation on human health and food waste could be quantified. The analysis also includes indicative evidence of impacts on international trade in food, but it was not possible to link this to the use of irradiation or origin authentication directly. This means that the benefits enabled by the RCA activities may be underestimated.

The analysis is based on estimates of the economic costs of foodborne diseases produced by the World Bank Group [VII–1] and modelling of the potential impacts of food irradiation on those costs and the costs of food waste. The contribution of the RCA activities to relevant policies, regulations and uptake of food irradiation is based on information from the survey of experts described in Annex VI. Direct and indirect costs of the relevant RCA activities were also estimated for comparison with costs. Benefits and costs were assessed over the period from 1999 to 2023.

The analysis suggests that it is likely that the RCA activities being evaluated enabled more benefits than the costs of the programme, by enabling increased uptake and use of food irradiation in some RCA State Parties (SPs) that helped to reduce costs of foodborne illnesses and food waste. **Across a wide range of assumptions, benefits enabled by the RCA activities exceeded costs in 72% of the scenarios tested.** There is evidence that the RCA activities enabled small but positive benefits in many cases, except the most conservative assumptions that were tested.

There is good evidence that the RCA activities being evaluated contributed to changes in food safety policies and standards in some RCA SPs, and these changes are likely to have contributed to improved food safety outcomes relative to outcomes in the absence of the RCA FS programme. However, as changes in food safety outcomes also depend on other factors, such as political support, investment by governments and businesses and behavioural change, it is not possible to directly attribute the estimated benefits to the RCA activities.

VII–2. Overview of the economic framework

VII–2.1. Objectives of the economic analysis

The economic framework seeks to evaluate the food safety RCA activities relative to the standards for the economic impact criterion that were developed for this evaluation:

- **Excellent (exceeding expectations):** Economic analysis suggests with a high level of certainty that the investment created more value than it consumed. Break-even is likely in nearly all scenarios (even under conservative assumptions used in the sensitivity analysis).
- **Good (meeting expectations):** Economic analysis suggests more likely than not, the investment created more value than it consumed. Break-even is likely in over half the range of scenarios (and under realistic mid-range assumptions used in the sensitivity analysis).
- **Adequate (meeting bottom-line expectations):** Economic analysis suggests that under some scenarios, the investment created more value than it consumed. Break-even is possible (under plausible assumptions used in the sensitivity analysis).
- **Minor (not meeting expectations):** Break-even is unlikely (or only possible under optimistic assumptions used in the sensitivity analysis).

These standards focus on the overall contribution of the food safety RCA activities to creation of value in RCA SPs. In this context, value is all potential sources of social value including impacts on human health and the environment, although in practice only some of these impacts can be analyzed with currently available information.

The economic framework described below is designed to support evaluation of these criteria and standards. It supports a broad assessment of whether the benefits enabled by RCA activities are likely to exceed the costs of those activities. It is not possible to precisely estimate the benefits associated with the food safety RCA activities being evaluated, due to the indirect link between these activities and economic outcomes. Given the substantial uncertainty about impacts, the framework focuses on assessing the strength of evidence for economic impacts and the likelihood that value created exceeds costs.

VII–2.2. Relevant RCA activities to be evaluated

The six RCA projects being evaluated were undertaken between 1999 and 2023 and received total nominal direct funding from the IAEA of around EUR 2.4 million over this period (Table VII–1). These projects promoted training, research, collaboration and knowledge transfer relating to food irradiation and nuclear techniques for food origin authentication among 22 SPs of the Asia-Pacific RCA.

Table VII–1. Summary of relevant RCA activities being evaluated.

Project	Category	Objectives	Direct funding
RAS5034 1999–2001	Irradiation	To implement a harmonized protocol on irradiation as quarantine treatment of fresh horticultural commodities; to implement national regulations on the basis of the "Harmonized Regulations on Food Irradiation for Asia and the Pacific"; to establish irradiation as an effective sanitary treatment to control pathogens in food trade; and to organize market tests of selected irradiated commodities.	€368 000
RAS5042 2001–2007	Irradiation	The overall objective is to improve food security, food safety and inter-country trade of food products by irradiating the products. The specific objectives are to facilitate the expansion of the use of food irradiation in Regional Co-operative Agreement countries and to improve international trade in irradiated food within the region through continued public awareness and acceptance of radiation processing of food and for sanitary and phytosanitary treatment; conducting inter-country market trials of irradiated food commodities; and training of personnel in specific fields, such as plant operation, microbial safety and phytosanitary requirements.	€332 000
RAS5050 2009–2012	Irradiation	To enhance treatment of and trade in irradiated products of economic importance in the Asia Pacific region.	€394 000
RAS5057 2012–2016	Irradiation	To enhance the effective application of irradiation technologies for sanitary and phytosanitary purpose of agricultural products.	€258 000
RAS5081 2018–2021	Origin authentication	To improve food safety, enhance consumer confidence and increase trade by establishing a robust and independent means of verification of origin of foodstuffs.	€719 000
RAS5087 2020–2023	Irradiation	To enhance food safety and trade in the region through developing and promoting electron beam and X ray technology for food irradiation.	€300 000

Five projects (70% of IAEA funding across the six projects) focused on irradiation of food, and one project (30% of IAEA funding) focused on using nuclear techniques for origin authentication of food products. The origin authentication project was relatively recent (2018–2021) while the irradiation projects spanned more than 20 years. For these reasons and due to data availability, most of the analysis below is concerned with food irradiation.

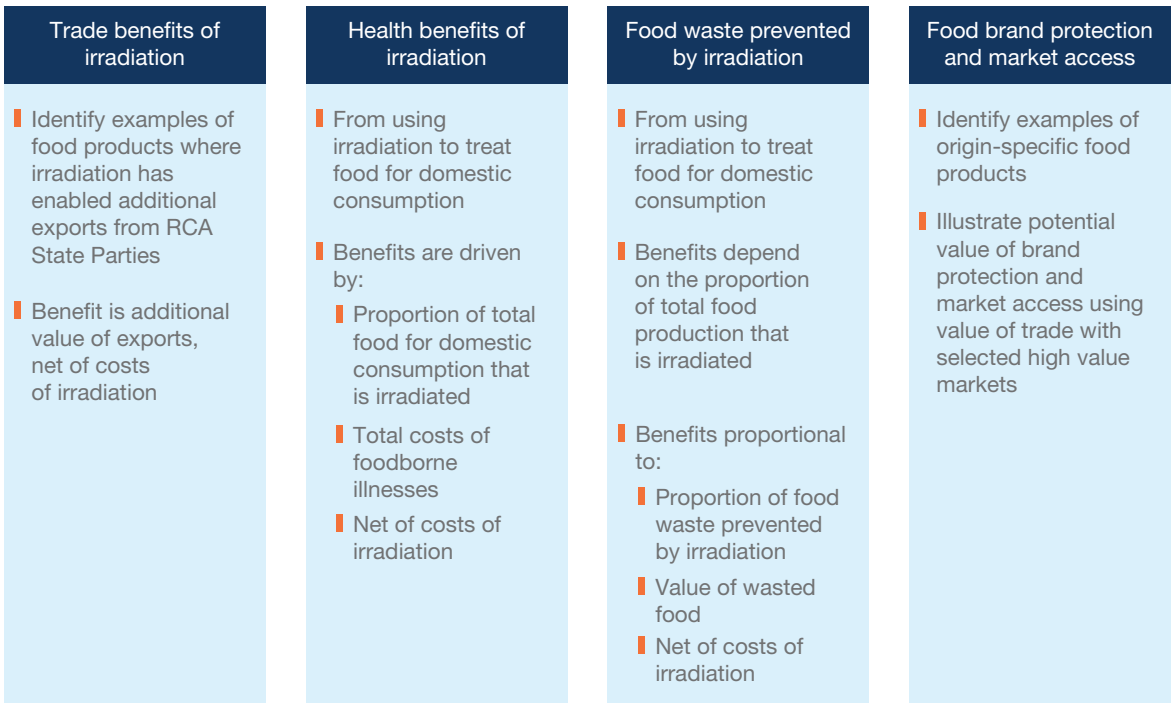
The combined impacts of the activities were evaluated over the 24-year period spanned by these projects, without assessing the individual contributions of the six projects separately. However, the economic analysis separates the potential impacts of irradiation and origin authentication due to the substantial differences between these activities. In addition, there are more data available to support analysis of food irradiation and the associated economic impacts could be modelled in more detail compared to origin authentication.

There were some variations in the extent to which the 22 RCA SPs participated in the relevant RCA activities. Based on project reports provided by the IAEA, all except Palau participated to some extent in at least one project out of the six projects being evaluated, but the number of SPs that participated in each of the projects ranged from 13 (RAS5042) to 21 (RAS5081 and RAS5087). These differences in participation were considered when evaluating both the benefits and costs of these RCA activities, but the economic evaluation is designed to assess the overall impacts of the RCA projects and the impacts for individual SPs are not estimated.

VII–2.3. Benefits enabled by RCA activities

During development of the evaluation framework, several potential categories of economic benefit that may be enabled by the RCA activities were identified. Figure VII–1 shows the sources of benefits that could potentially be quantified. In addition, other benefits that were not expected to be possible to quantify were also identified, such as environmental benefits.

FIG. VII–1. Sources of benefits from food safety RCA activities.



In practice, due to data limitations and the nature of the RCA activities, it was not possible to quantify all potential types of benefit shown in Fig. VII–1. The modelled benefits enabled by the RCA activities being evaluated are *costs of foodborne illnesses avoided*, and *costs of food waste avoided* due to use of food irradiation in RCA SPs.

Impacts of irradiation and origin authentication on international trade in food products were also considered but impacts enabled by the RCA activities could not be quantified due to limited data on exports of irradiated food products, limited uptake of origin authentication at this stage and uncertainty about the actual effects of both irradiation and origin authentication on trade volumes.

VII–2.4. Costs of RCA activities

Costs of the food safety RCA activities being evaluated include:

- Direct funding provided by the IAEA (see Table VII–1).
- The opportunity costs of time associated with participation in these activities by experts and others in RCA SPs.

Direct costs are based on information provided by the IAEA about funding approvals for the relevant RCA projects. Other costs are estimated based on records of activity provided by the IAEA for these projects, including participation in relevant meetings and workshops.

VII–2.5. Comparing benefits and costs

Benefits and costs associated with RCA activities are compared by calculating the present value of real benefits and costs over the period from 1999 to 2023. All benefits and costs are expressed in real 1999 Euro and were discounted back to 1999 using an average real discount rate for RCA SPs of 10.2% in the baseline scenario (see below). The present value calculation accounts for the fact that benefits and costs that occur later in time are less valuable than those that occurred earlier. Benefits and costs are discounted back to 1999 to give a comparison of benefits and costs as at the beginning of the RCA activities for food safety that are being evaluated.[1]

The net present value of economic benefits enabled by RCA activities is the estimated difference between the present value of benefits and the present value of costs. If the net present value is positive, the RCA activities enabled more benefits than the associated costs.

Sensitivity testing was done to estimate and compare benefits and costs under alternative assumptions, to account for the uncertainty associated with these model inputs. This involved defining alternative 'low' and 'high' values of each parameter of the economic model around a 'baseline' value. Results were generated for all possible combinations of low, baseline and high assumptions for all parameters of the model.[2] The sensitivity analysis was summarized by calculating the proportion of these scenarios in which estimated benefits enabled by the RCA activities were greater than costs and by calculating the distribution of net present value across the scenarios. The sensitivity analysis is intended to assess whether the results are robust to alternative assumptions, including assumptions that are very different from the baseline assumptions.

VII–2.6. Discount rate

The discount rate used in the analysis reflects the time value of money. For example, costs incurred in the early years of the evaluation period could have been invested in alternative activities that would have generated a return on investment over time. The magnitude of the discount rate reflects the extent to which benefits and costs occurring later in time have lower value than those occurring earlier in time.

The baseline discount rate used in this analysis was set by assigning the RCA SPs to low, medium and high risk categories and assuming discount rates of 5%, 10%

[1] Discounting benefits and costs back to the start of the relevant activities (1999) makes the methodology used for this evaluation consistent with what would have been done in a forward-looking assessment of expected future benefits and costs of the RCA activities at that time. As most of the benefits enabled by the RCA activities occur at the end of the evaluation period, this is a conservative assumption that tends to reduce the estimated net benefits. An alternative approach of inflating past values forward to the end of the evaluation period would produce larger estimates of net benefits.

[2] This is equivalent to assuming that the low, baseline and high values are equally likely for each parameter and that the parameter values are all independent of each other.

and 15% for these categories respectively. Averaging gives the baseline discount rate of 10.2%. In sensitivity analysis, alternatives of 5.2% and 15.2% were tested.

VII–2.7. Limitations of the economic analysis

There are limited data on food irradiation volumes, costs of foodborne illnesses and costs of food waste in RCA SPs. Due to these limitations, the analysis uses a simplified approach to produce indicative estimates of the benefits enabled by food safety RCA activities (described below). The assumptions used in the analysis mean the benefits associated with RCA activities are directly proportional to the volume of food that is irradiated in RCA SPs, but there is limited and uncertain information about this volume over time. This is partly because irradiation is done by private companies and volume information is commercially sensitive. Alternative scenarios for food irradiation volumes were therefore considered in the sensitivity analysis (see below).

A key step in the analysis is translating participation in RCA activities and the information provided by experts in RCA SPs about impacts of the RCA activities into benefits enabled by the RCA. This is done using an impact model described below; however, as there is substantial uncertainty in this translation it is designed to be conservative, and a range of alternative assumptions are tested.

In addition, the costs of irradiating food in RCA countries are not explicitly modelled due to lack of sufficiently detailed information about irradiation volumes and costs. However, costs of food irradiation are borne by food producers and exporters and are recovered in the selling prices of irradiated food. It can be assumed that the private benefits to food producers of using irradiation at least equal their private costs (otherwise they would not choose to use irradiation). This means that the net of private benefits over costs of using irradiation can be assumed to be close to zero for private food producers.[3]

Given the substantial uncertainties described above associated with assessing the causal impacts of the RCA activities on food safety outcomes and economic activity, the economic evaluation focuses on assessing how likely it is that these activities enabled benefits that are greater than their costs. It is not possible to say that the food safety RCA activities directly generated some dollar value of benefits. Instead, the estimated impacts were enabled by RCA activities but also required significant additional actions and/or commitments of resources by RCA SPs to achieve. It is not possible to separate the contribution of the RCA activities from other such factors.

[3] To avoid double counting, part of the benefits of food waste avoided are assumed to be part of the private benefit to food producers of using food irradiation and are not included in the model of benefits enabled by RCA activities (i.e. only the consumer proportion of the food waste benefit is counted as an impact of RCA activities).

VII–3. Estimated gross benefits enabled by food safety RCA activities

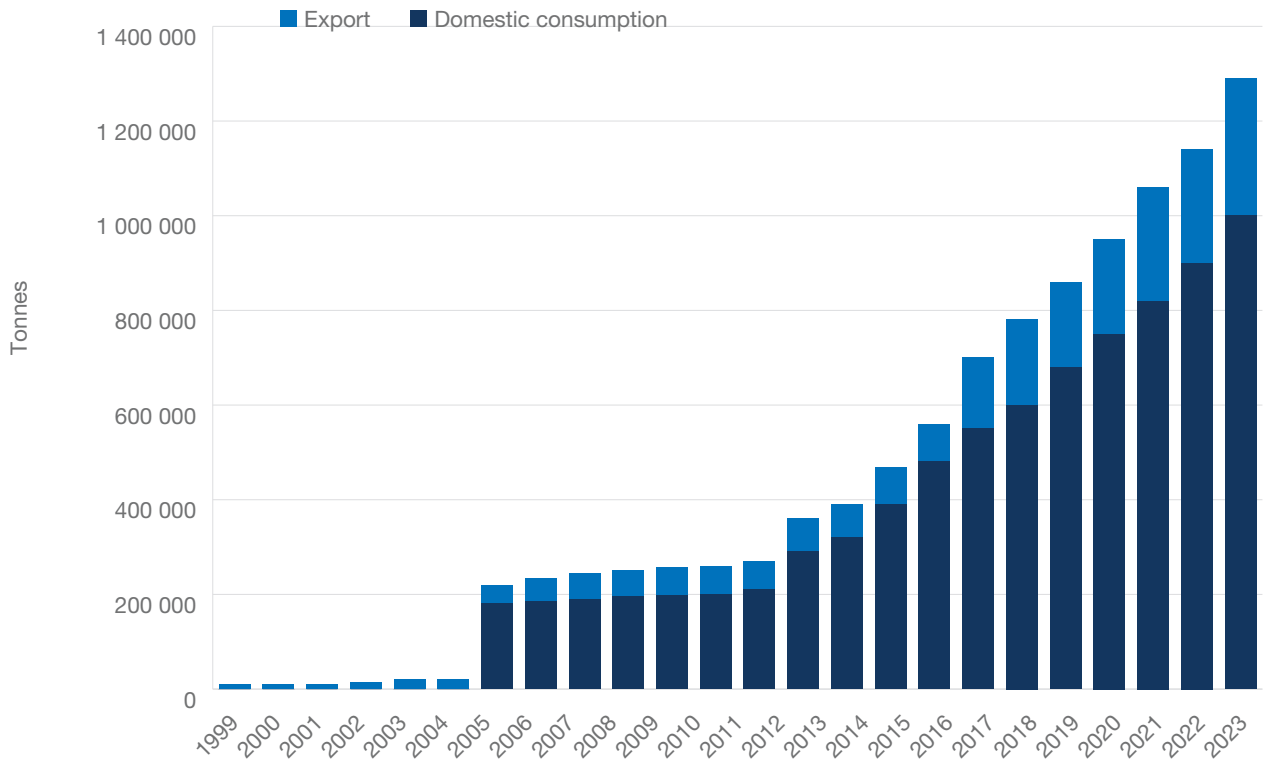
VII–3.1. Estimated food irradiation volumes in RCA countries

As described above, the estimated benefits enabled by RCA activities are directly proportional to the quantity of food irradiated in RCA SPs. Some historic information about irradiation volumes was provided by the IAEA and additional information was collected from experts in RCA SPs. This information was combined, and where there was overlap or conflict, data from the expert survey were preferred (as it is more recent) and included a breakdown of food irradiated for domestic consumption versus for export.

Volume information was collected for the years 2000, 2005, 2010, 2015 and 2020. Some countries did not provide irradiation volumes for some years, so the change in irradiation volumes over time partly reflects changes in data availability as well as changes in actual volume. Volumes for other years that were in between the years collected in the survey were estimated using linear interpolation.

The resulting total annual food irradiation volume estimates across all RCA SPs are shown in Fig. VII–2. This shows strong growth in volumes, particularly for domestic consumption, but as noted above some of this growth is due to changes in data availability.

FIG. VII–2. Estimated total annual volume of food irradiated in RCA SPs per year.

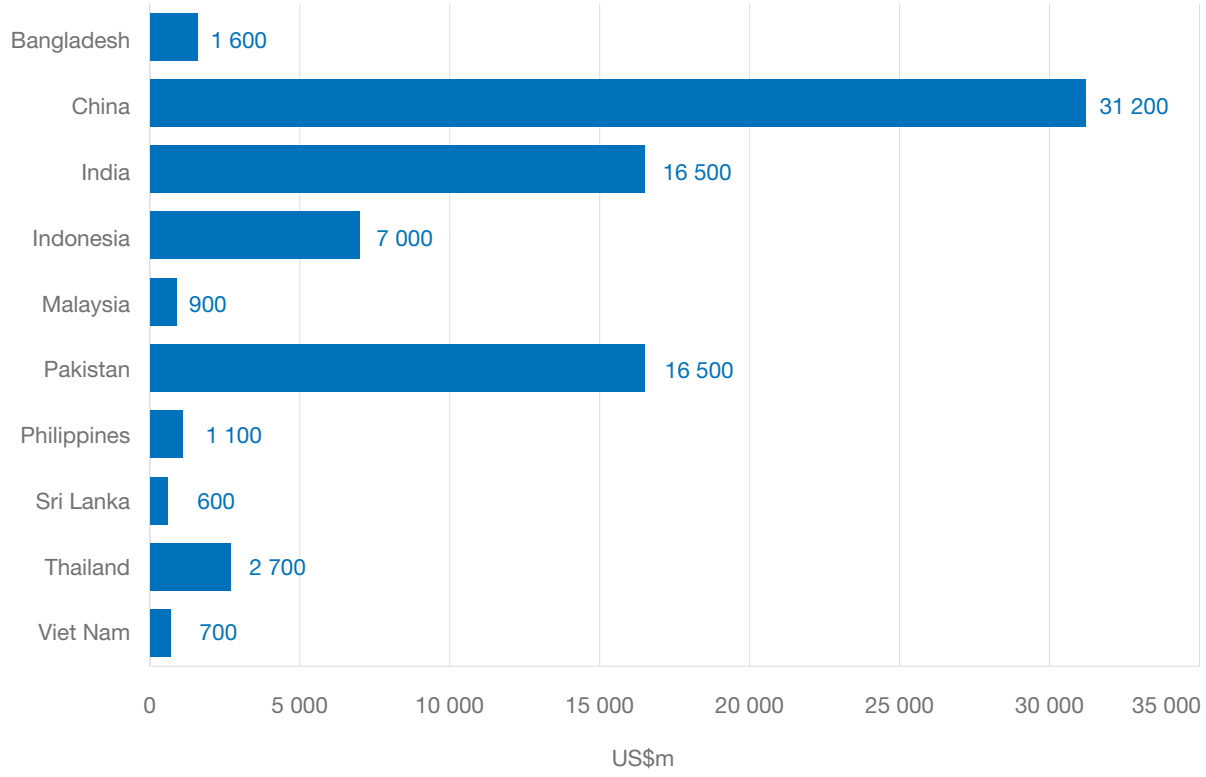


In 2023 it is estimated that around 1 million tonnes of food was irradiated in RCA SPs for domestic consumption and around 273 000 tonnes was irradiated for export. The estimated volumes of food irradiated in RCA SPs are quite small relative to total volumes of food consumed. Based on data from the Food and Agriculture Organization of the United Nations (FAO), around 3.15 billion tonnes of food was consumed in RCA SPs in 2023 [VII–2]. Estimated food irradiation volumes are less than 0.05% of this total.

VII–3.2. Estimated costs of foodborne illnesses avoided due to the use of irradiation

Estimates of the social costs of foodborne illnesses were estimated by the World Bank (2019) for ten RCA SPs (Fig. VII–3) [VII–1]. Estimates are not available for other countries or other years. However, the countries that are included in the World Bank's estimates make up around 92% of the total population of the RCA SPs, therefore the costs of foodborne illnesses in the omitted countries are expected to be relatively small.

FIG. VII–3. Estimated costs of foodborne illnesses in selected RCA SPs in 2018 [VII–1].



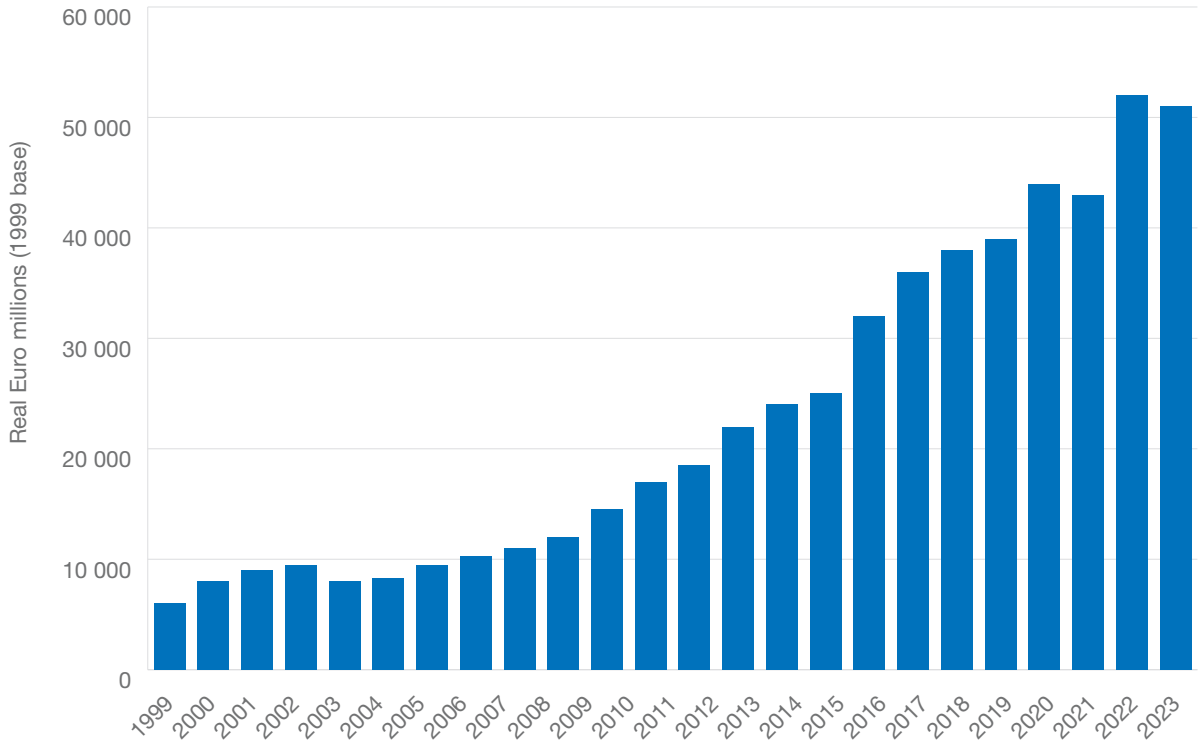
Annual costs of foodborne illnesses from 1999 to 2023 were estimated for each RCA SPs for which the World Bank estimates are available by scaling the cost estimate for 2018 by the ratios of population and GDP per capita relative to

2019. Specifically, the cost of foodborne illnesses in country *i* and in year *t* was estimated based on population in that year ($P_{i,t}$) and GDP per capita in that year ($G_{i,t}$) relative to 2018:

$$C_{i,t} = C_{i,2018} \times \frac{P_{i,t}}{P_{i,2018}} \times \frac{G_{i,t}}{G_{i,2018}} \qquad \text{VII-1}$$

The resulting estimate of the total annual costs of foodborne diseases in RCA SPs is shown in Fig. VII–4. This increases over time due to population and economic growth. Due to data limitations, changes in other factors such as improvements to food safety systems and changes in the prevalence of foodborne diseases are not accounted for. This means that the costs of foodborne diseases are likely to be underestimated in earlier years.

FIG. VII–4. Estimated total annual real costs of foodborne illnesses in RCA SPs per year.



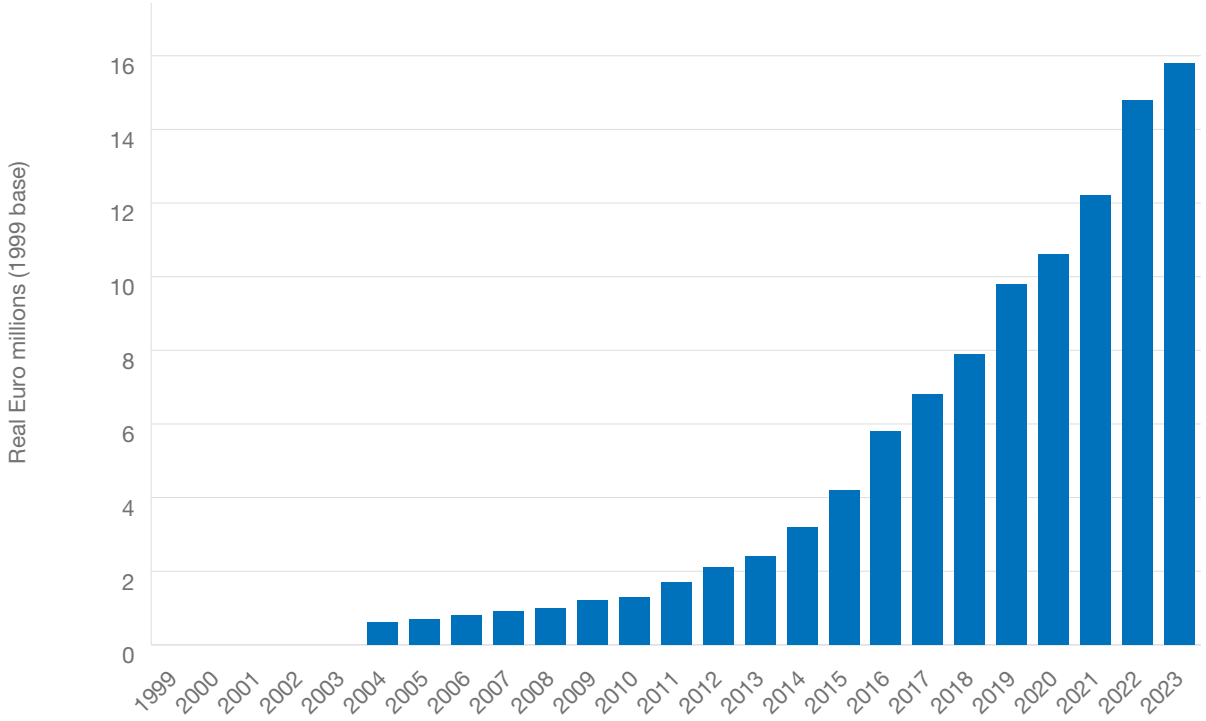
Due to limited data about the types of food irradiated and the relationships between different types of food and foodborne illnesses, an indicative estimate of the value of foodborne illnesses prevented due to the use of irradiation is calculated by assuming that this is proportional to the volume of food irradiated for domestic consumption (see above) as a percentage of the total volume of food consumed in RCA SPs.[4]

[4] It is less likely that irradiation of exported food prevents foodborne illnesses, due to stricter quality controls on exported products. In addition, there is limited information about the types and destinations of irradiated food products from RCA countries which makes it difficult to estimate the benefits of preventing foodborne illnesses in foreign countries.

Data on the total volume of food consumed in RCA SPs were obtained from the FAO. Food that was irradiated for domestic consumption was around 0.03% of total food consumption in RCA SPs in 2023. The resulting estimated costs of foodborne illnesses in RCA SPs that were avoided due to the use of irradiation is shown in Fig. VII–5. This increased over time due to both the increase in volume of food irradiated for domestic consumption (see above) and increase in costs of foodborne illnesses over time (see Fig. VII–4).

The estimates shown in Fig. VII–5 are for total costs of foodborne illnesses that were prevented due to the use of irradiation (i.e. one dimension of the benefits of food irradiation in RCA SPs). The contribution of the RCA activities being evaluated to these benefits is assessed using an impact model, which is described below.

FIG. VII–5. Estimated real costs of foodborne illnesses avoided in RCA SPs due to use of irradiation per year.



VII–3.3. Estimated costs of food waste avoided due to use of irradiation

No prior estimates of the total costs of food waste in RCA SPs were able to be located. Instead, it was assumed that irradiating food led to a reduction in spoilage and wastage that was proportional to the volume and value of food irradiated. Using FAO data on food prices for perishable fruit and vegetable products, an average value per tonne of irradiated food was estimated for each RCA SP.[5] This

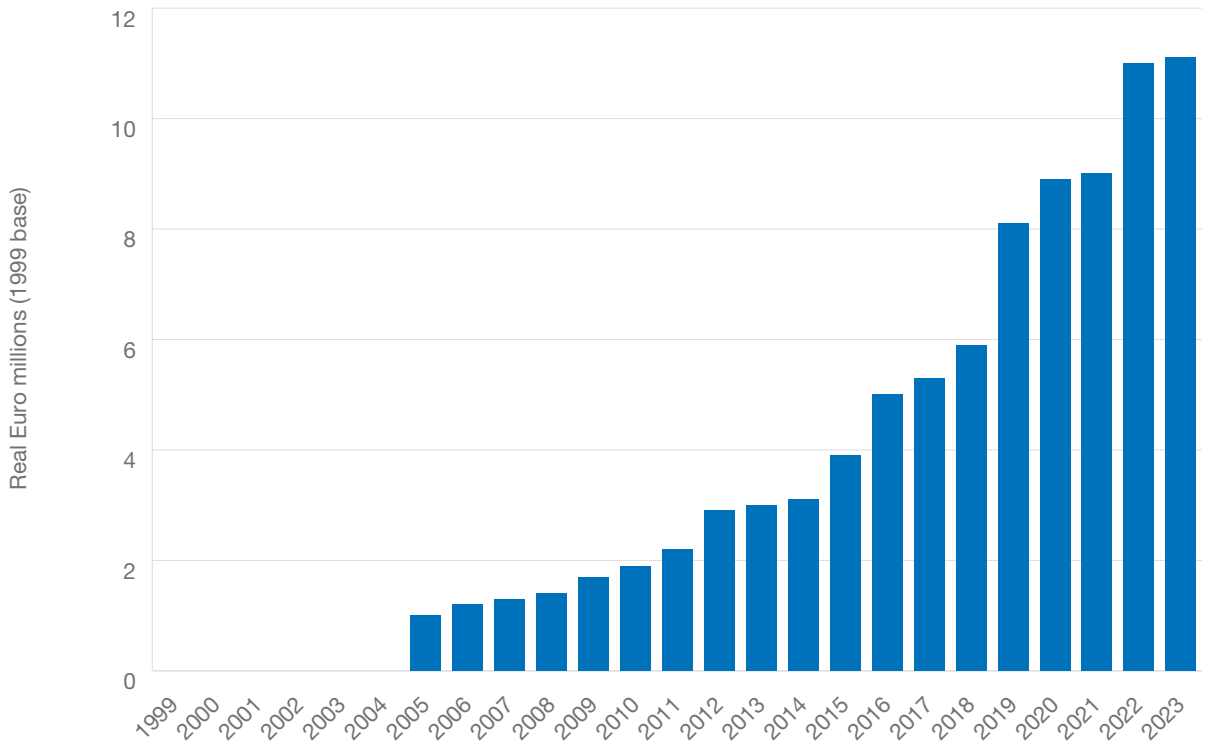
[5] Other types of food including herbs and spices, meat and seafood are also irradiated but data limitations meant it was not possible to include these in the average price estimates.

was applied to the total volumes of food irradiated (see above) to estimate the value of irradiated food. Under the baseline assumptions, it is assumed that 5% of this value is food waste that is avoided due to the use of irradiation.[6]

The estimated value of food waste avoided was calculated using the combined domestic and export volume of irradiated food, as both should benefit from improvements in quality and shelf life provided by irradiation. Only the consumer proportion of this benefit was included in the economic analysis. The proportion of the benefit of food waste avoided that accrued to food producers was assumed to be offset by costs incurred to irradiate food, which were not explicitly modelled for the reasons explained above. Under the baseline assumptions, the consumer benefit is assumed to be 50% of the estimated total value of food waste prevented.

The resulting estimates for the consumer value of food waste prevented across RCA SPs due to the use of irradiation are shown in Fig. VII–6. This increased over time primarily due to the increase in the volume of food irradiated. As with prevention of foodborne illnesses, the contribution of the RCA activities to this benefit are estimated using an impact model, which is described below.

FIG. VII–6. Estimated real value of food waste prevented in RCA SPs due to the use of irradiation per year (consumer proportion).



[6] This assumes that 25% of perishable food that is produced is wasted, and that irradiation prevents around 20% of wastage. Alternative assumptions are tested as part of the sensitivity analysis described below.

VII–3.4. RCA impact model for food irradiation

Food safety experts in RCA SPs were surveyed to assess the extent to which food safety RCA activities enabled four relevant domains of change relating to the use of food irradiation:

- New regulations or changes to existing regulations that support food irradiation;
- Policy decisions and interventions related to food irradiation;
- Impact of the RCA programme on domestic consumption of irradiated food;
- Impact of the RCA programme on exports of irradiated food.

For each of these four domains, experts were asked to rate the impact of RCA activities on a scale of not enabled, minor impact, some impact or significant impact. Responses to these questions in the survey of experts were received from 18 SPs. Impacts were not modelled for the SPs that did not respond to the survey for food irradiation (India, New Zealand, Palau and Singapore).[7]

The relevant summary responses are summarized in Annex VI. There is evidence to support impacts of the RCA activities in several SPs, including China, Indonesia, Malaysia and Sri Lanka. Survey responses and other data was also used to estimate the first year that RCA activities were assumed to have impacts on actual food safety outcomes (if any). In most cases, the first two RCA projects being evaluated had been completed in 2010 and the third project was underway (see Table VII–1). Other dates are based on information provided by survey respondents about when each SP started to participate in the RCA activities. In all cases these were later than 2010.

For modelling purposes, the survey responses were translated into estimated RCA impacts (i.e. estimates of the proportions of benefits of food irradiation that were enabled by RCA activities). These estimates are intended to be indicative of the impact of the RCA activities and are not a precise estimate of economic benefits associated with those activities. This is because, in practice, the RCA activities were just one factor among many that affected uptake and usage of food irradiation and corresponding impacts on foodborne illnesses and food waste.

An overall RCA impact factor was calculated for each SP by assigning scores to the relevant survey responses and averaging these scores across the four domains of change. The assumed response scores under baseline and alternative low and high assumptions are summarized in Table VII–2.

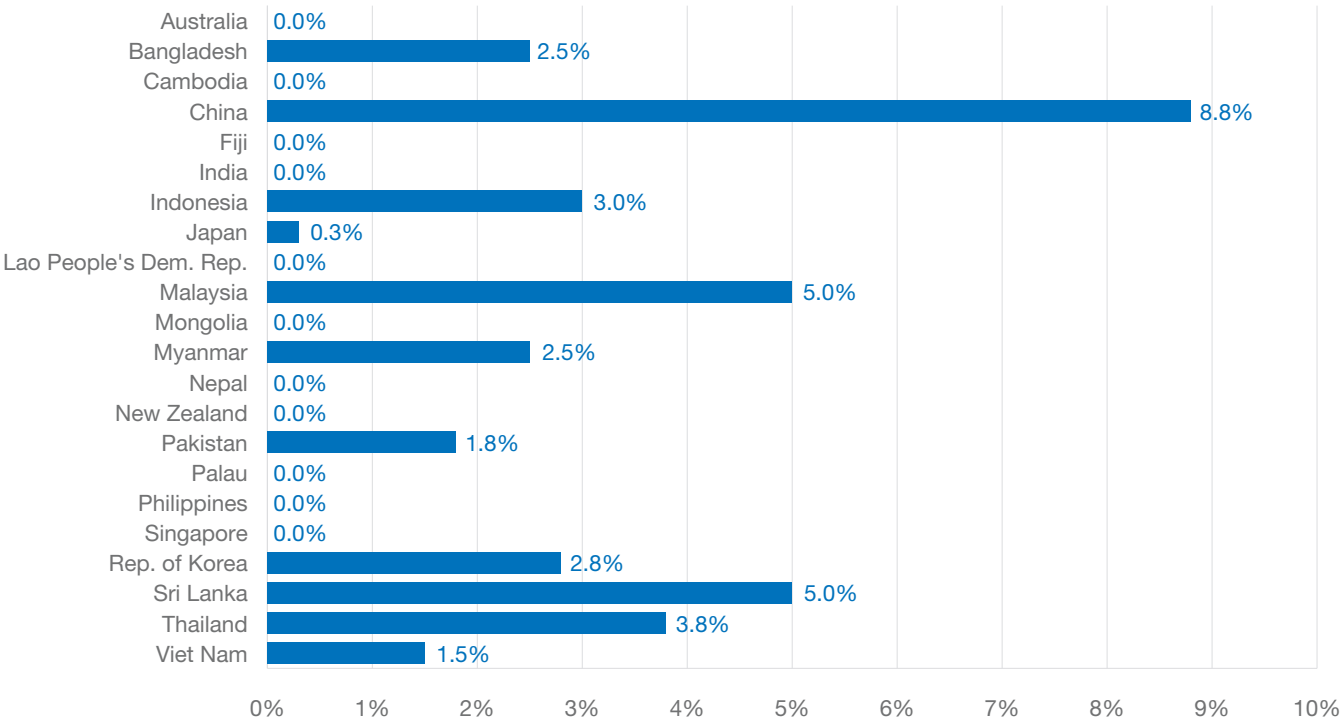
[7] Among these countries, food irradiation is not understood to be used in New Zealand, Palau and Singapore.

Table VII–2. Summary of RCA impact model assumptions.

Response	Low	Baseline	High
No response	0.0%	0.0%	0.0%
Not enabled	0.0%	0.0%	0.0%
Minor impact	0.5%	1.0%	1.5%
Some impact	2.5%	5.0%	7.5%
Significant impact	5.0%	10.0%	15.0%

The average RCA impacts based on the survey responses are shown in Fig. VII–7 for the baseline assumptions. It is assumed that these proportions of the benefits of foodborne illnesses avoided and food waste avoided were enabled by the RCA activities being evaluated.

FIG. VII–7. Baseline estimates of the proportion of foodborne illness and food waste costs that RCA activities enabled to be avoided in RCA SPs.

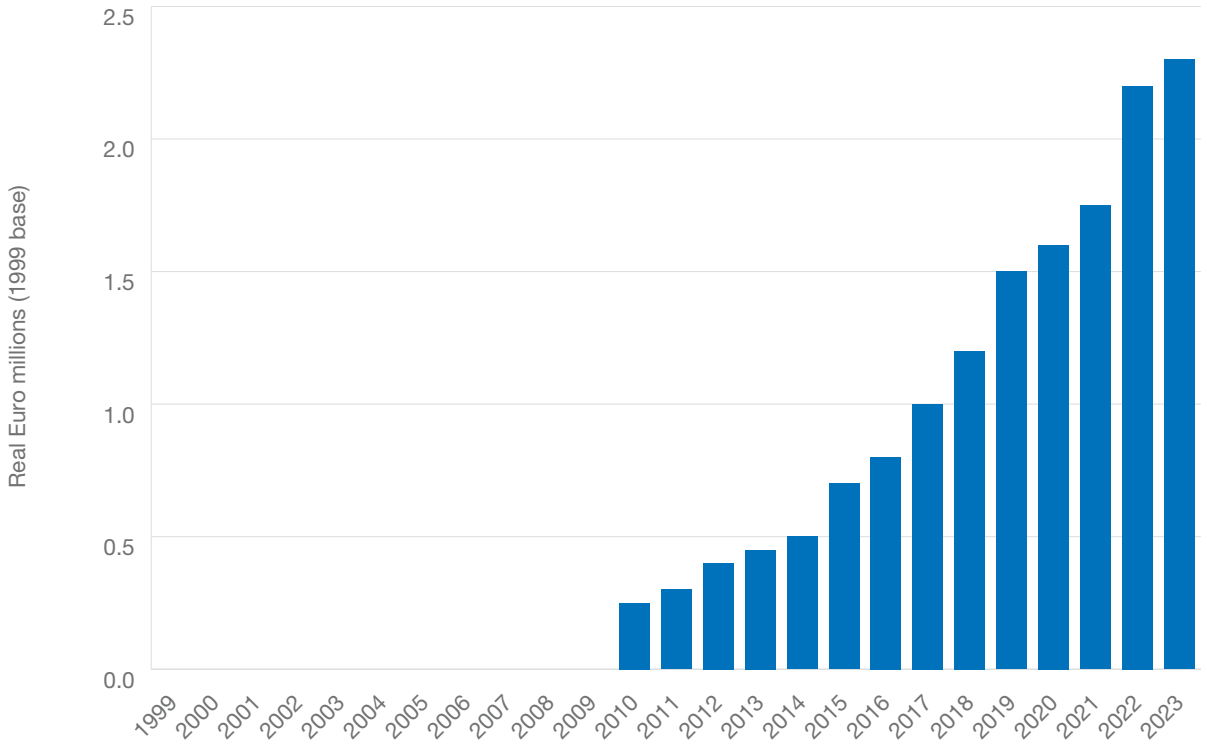


VII–3.5. Estimated benefits enabled by RCA activities

Combining the RCA impact model described above with the estimated benefits of foodborne illnesses and food waste prevented gives estimated benefits enabled by RCA activities (Fig. VII–8, for baseline assumptions). These increase over time in line with the increase in benefits estimated for using food irradiation in RCA SPs. It is likely that impacts will continue beyond 2023, but this has not been modelled

as it would require forecasting future food irradiation and food consumption volumes. In real present value terms (1999 base) the estimated benefits enabled by RCA activities are around EUR 2.3 million, under baseline assumptions.

FIG. VII– 8. Baseline estimates of real benefits enabled by food safety RCA activities.



VII–3.6. Additional evidence of impacts of irradiation on food exports

A principal use of food irradiation is as a phytosanitary treatment. This can be used to enable or improve exports of fruit and vegetable products to countries that restrict imports to prevent the spread of pests and diseases. The economic costs of such pests and diseases can be substantial and have been estimated at US$70 billion per year globally [VII–3]. Use of irradiation is likely to prevent some of these costs, but due to the irregular frequency and scale of pest and disease outbreaks it is difficult to predict the value of such avoided costs.

Irradiation could enable additional exports by helping exporters to meet the sanitary and phytosanitary requirements of importing countries. Irradiation could also be a superior alternative to options such as chemical fumigation or heat treatment. Experts in RCA SPs were asked to identify specific examples of where irradiation was used to enable food exports from their country to one or more other countries. Data from the United Nation's Comtrade database were then used to analyze trends in the value of exports for those examples.

In total, eight examples were identified that could be matched to available international trade data (Fig. VII–9A and B). In most cases, these show an increase in the value of exports following the introduction of irradiation. It is not possible to estimate the corresponding benefits from using irradiation because exports are affected by many other factors over time including economic conditions and trade policies. In addition, it is not clear whether these trends reflect substitution of exporters from other markets and/or substitution of food producers from other types of food products that would need to be considered in an analysis of net impacts on trade.

However, the trends observed are consistent with food irradiation having a positive impact on exports of food products from some RCA SPs, and some respondents to the expert survey indicate that the RCA activities contributed to these impacts. This is supportive of additional economic benefits enabled by RCA activities that were not able to be quantified.

FIG. VII–9A. Examples of trends in the value of irradiated food products exported from RCA SPs.

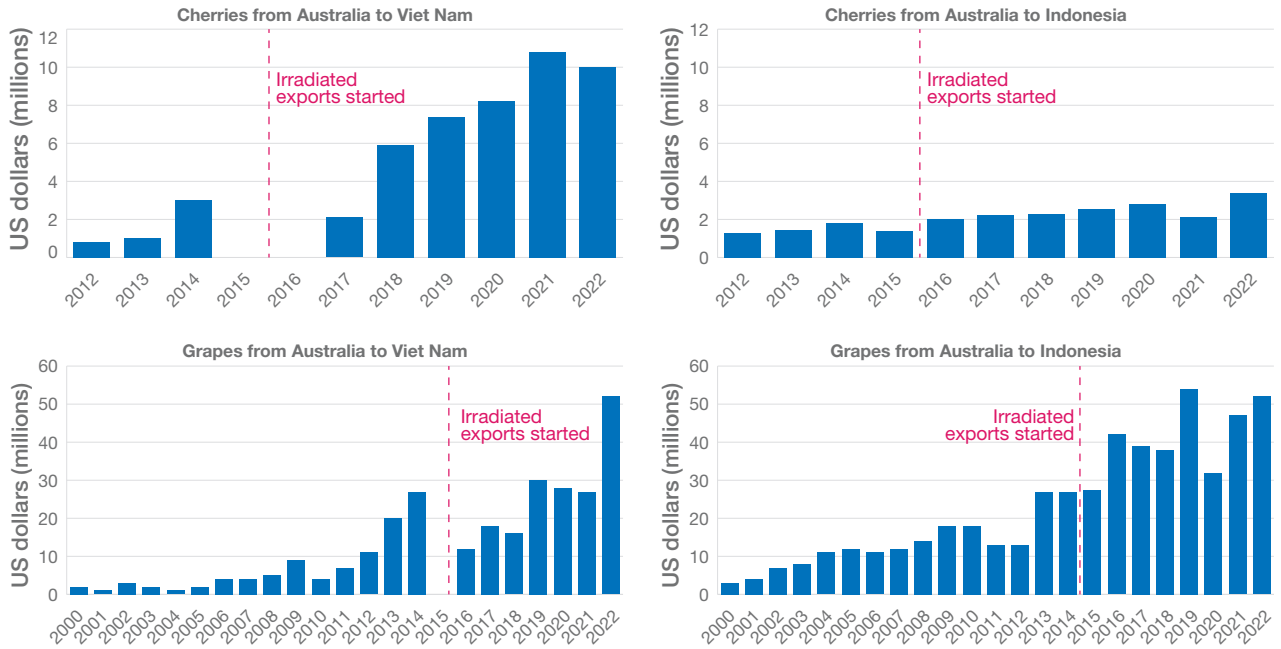
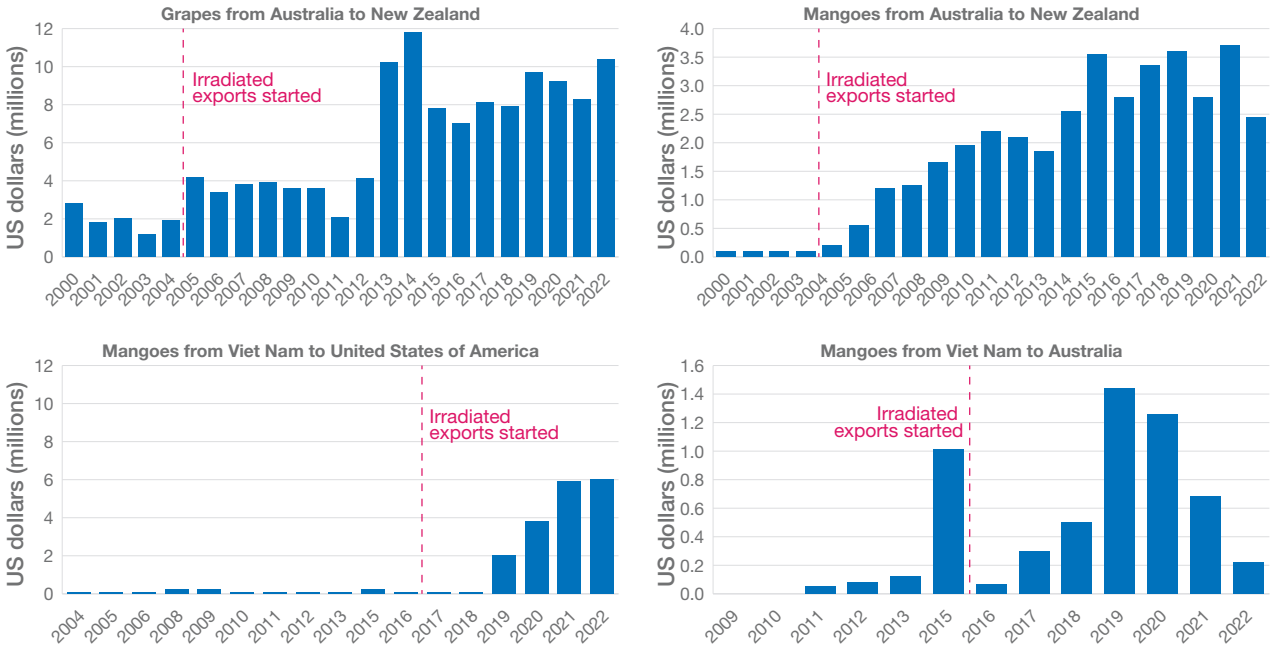


FIG. VII–9B. Examples of trends in the value of irradiated food products exported from RCA SPs.



VII–3.7. Additional evidence about origin authentication and trade

One of the six RCA projects being evaluated (RAS5081) is related to the use of nuclear techniques for origin authentication of food products. Authentication verifies claims about characteristics such as geographic origin, method of production and product composition, allowing consumers to make informed choices. It also helps detect some types of illegal adulteration or advantageous contamination, which supports regulatory bodies in enforcing food safety and labelling standards and protecting consumers.

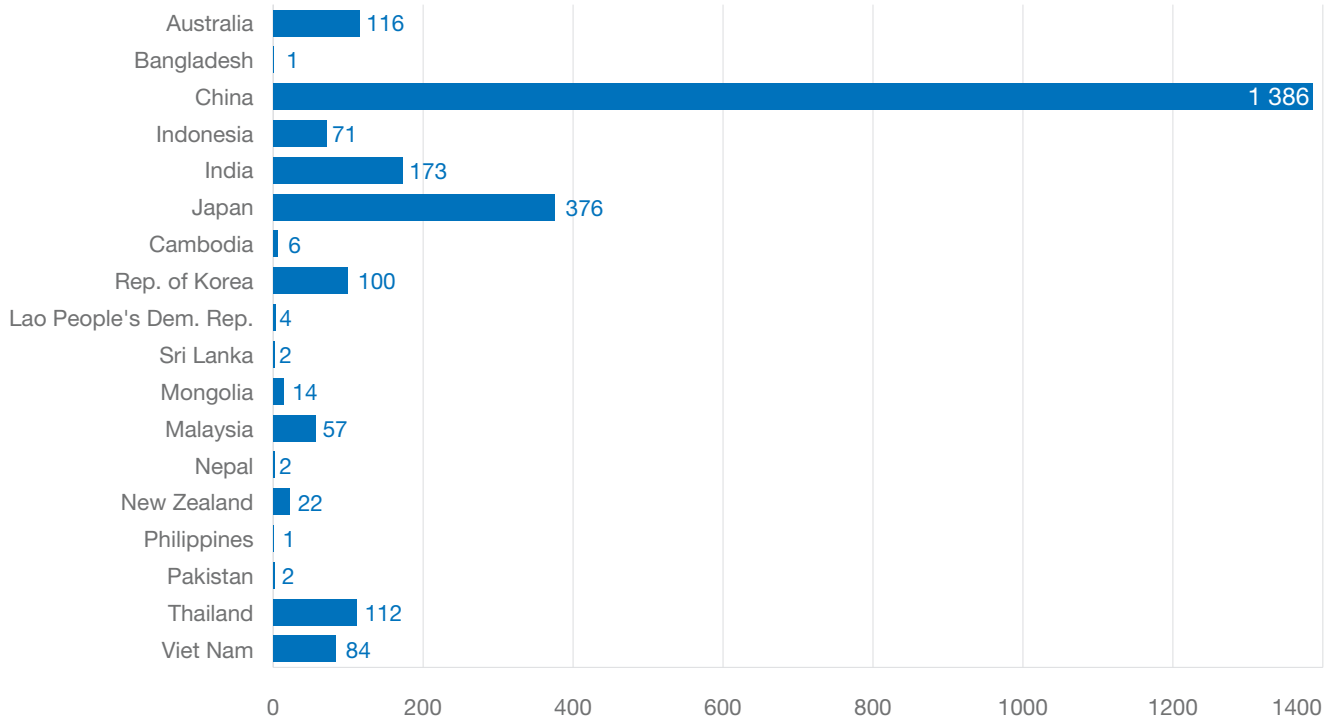
It was not possible to directly estimate the economic impacts enabled by the RCA project relating to origin authentication. One reason is that structured data on the use of nuclear techniques for origin authentication in RCA countries are not available. The final report for RAS5081 identified food products produced and/or consumed in countries for which origin authentication could be used in initial studies, but the extent to which this is done in practice is not tracked, and changes over time are not known.

In addition, the potential impacts of using origin authentication are diffuse and include enabling and/or maintaining access to export markets, reduced costs of food safety incidents, product development and protection, improved regulatory benefits and environmental benefits. Many other factors also contribute to these outcomes, and it is not possible to estimate the contribution of the RCA activities being evaluated. Finally, the RCA project relating to origin authentication was completed relatively recently (2018 to 2021) and economic impacts are likely to have been limited in scope and duration so far.

One of the key impacts of origin authentication is expected to be promotion of international trade in goods where origin is an important characteristic. Authentication of food origin is an increasingly important part of complying with regulations in some markets, such as country of origin regulations, or other regulations relating to geographic origin and ethical or sustainable production. Using standard and recognized authentication techniques is becoming increasingly important to enable and maintain access to high-value export markets such as the United Kingdom and the European Union. Countries that do not have access to suitable techniques could face non-tariff barriers to trade in the form of origin authentication requirements and regulations.

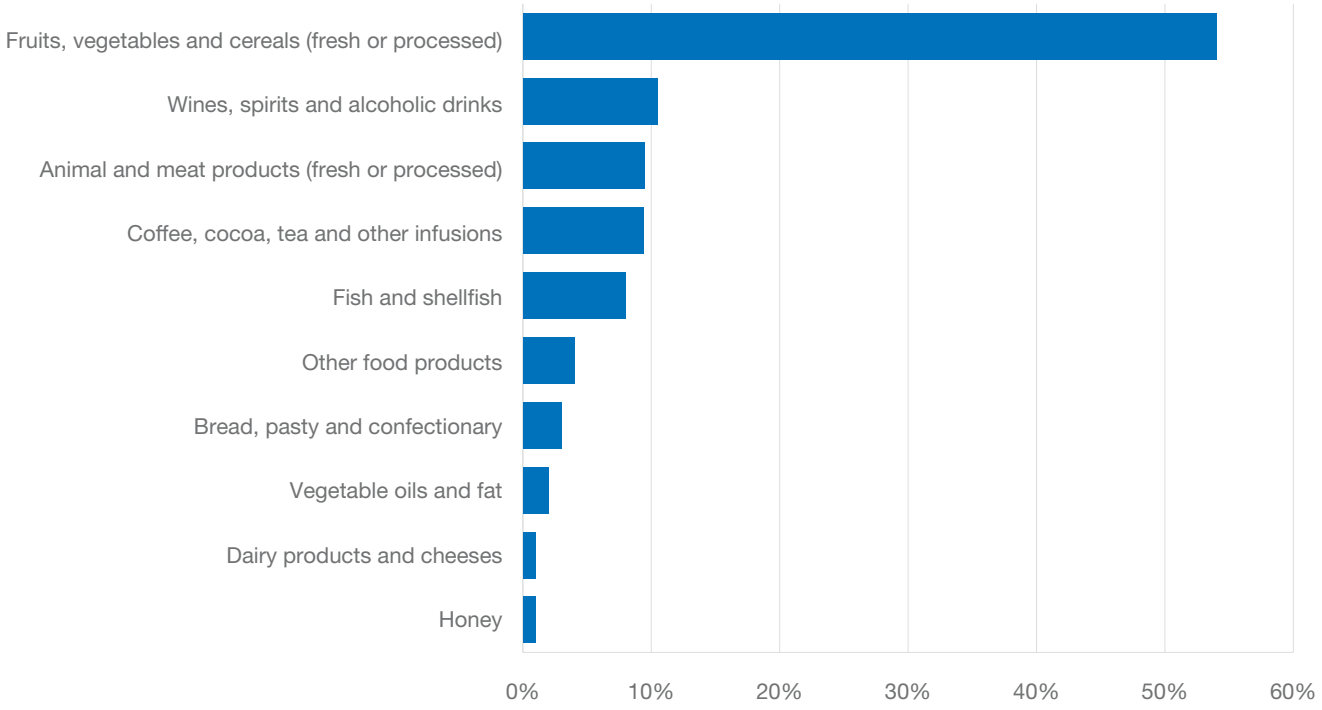
To illustrate the potential importance of origin authentication as an enabler of international trade, Fig. VII–10 shows the number of distinct food products with definitive geographic characteristics (i.e. geographic indications) formally registered by RCA SPs. In total, more than 2500 products with a geographic origin attribute as a defining characteristic have been registered by RCA SPs.

FIG. VII–10. Number of food products with registered geographic indications in RCA SPs [VII–4].



More than half of these products with registered geographic indications are fruits, vegetables and cereals (Fig. VII–11). Geographic indications have also been registered for major categories of primary products including coffee and tea, dairy products and honey.

FIG. VII–11. Categories of food products with registered geographic indications in RCA SPs [VII–4].

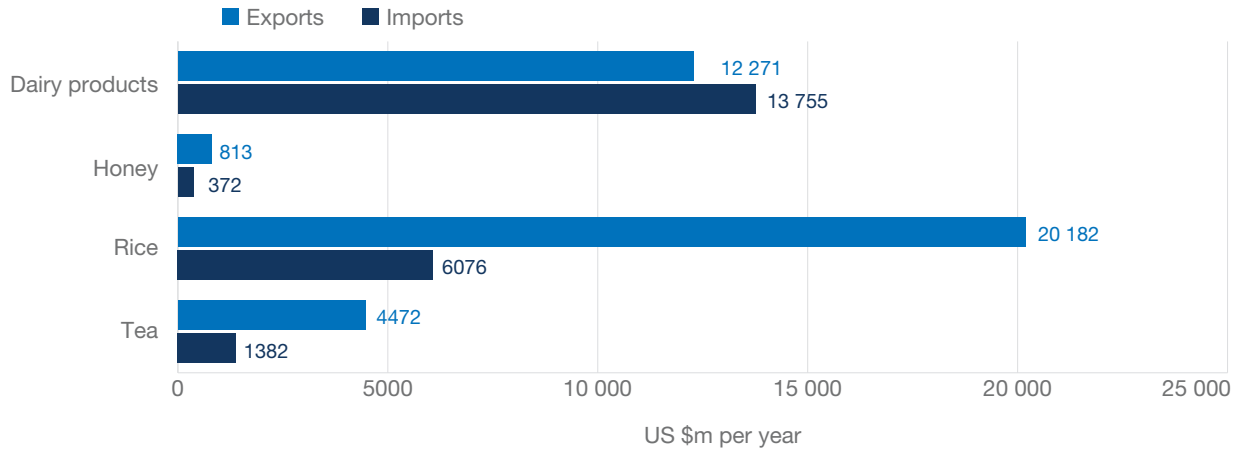


It is difficult to find data on the value of trade associated with specific products with geographic origin characteristics, but the following were identified for RCA SPs:

- Exports of jasmine rice from Cambodia were estimated to be worth US$430 million in 2023 [VII–5, VII–6].
- Exports of Darjeeling tea from India were around US$60 million in 2022 [VII–7, VII–8].
- Exports of Mānuka honey from New Zealand were NZ$335 million in 2023 [VII–9].
- Exports of Ceylon tea from Sri Lanka were around US$1.3 billion in 2023 [VII–10].
- Exports of Thai Hom Mali rice from Thailand were around THB43 billion in 2023 [VII–11].

In addition to the specific examples above, Fig. VII–12 shows total exports and imports across RCA SPs for categories of food products where origin authentication could be useful, including types of products that were tested as part of RAS5081. This shows substantial values associated with exports of these products that origin authentication can assist to protect and/or promote. While not directly linked to the RCA activities being evaluated, this provides evidence of the potential for origin authentication to create economic value in RCA SPs.

FIG. VII–12. Total trade by RCA SPs in categories of food products where geographic origin authentication could be valuable [VII–12].

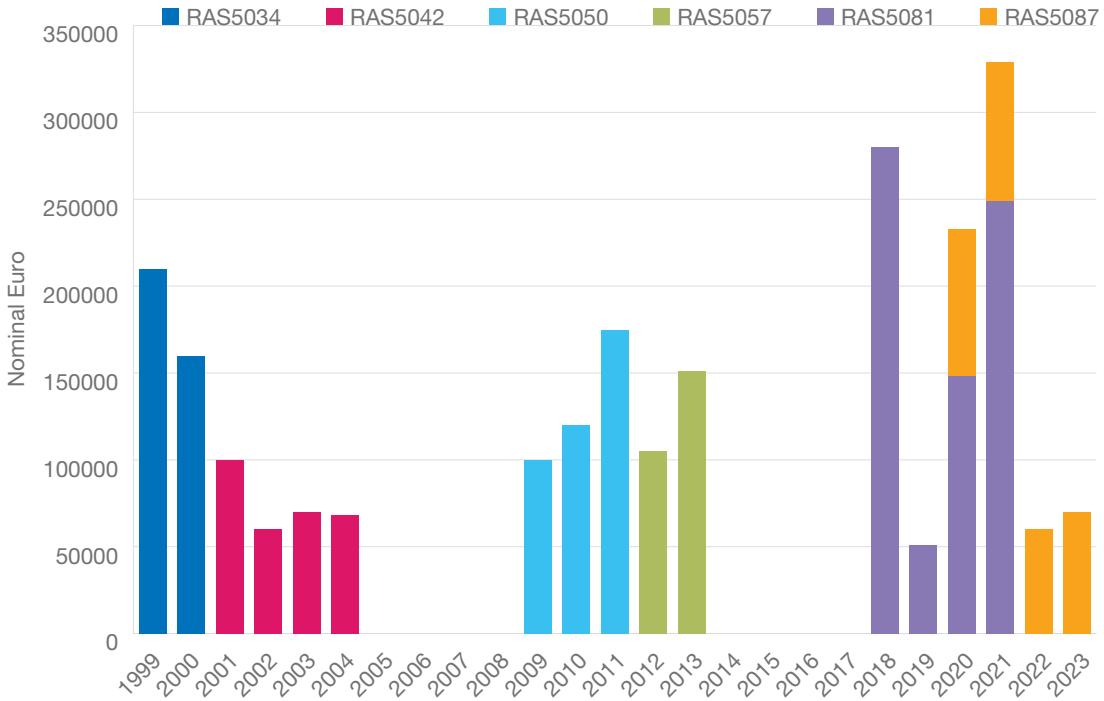


VII–4. Estimated costs of food safety RCA activities

VII–4.1. Direct funding from the IAEA

Information about direct funding from the IAEA was provided for the RCA projects shown in Table VII–1 (Fig. VII–13). Annual nominal funding was converted to real 1999 Euro using the average European Union-area consumer price index published by Eurostat.

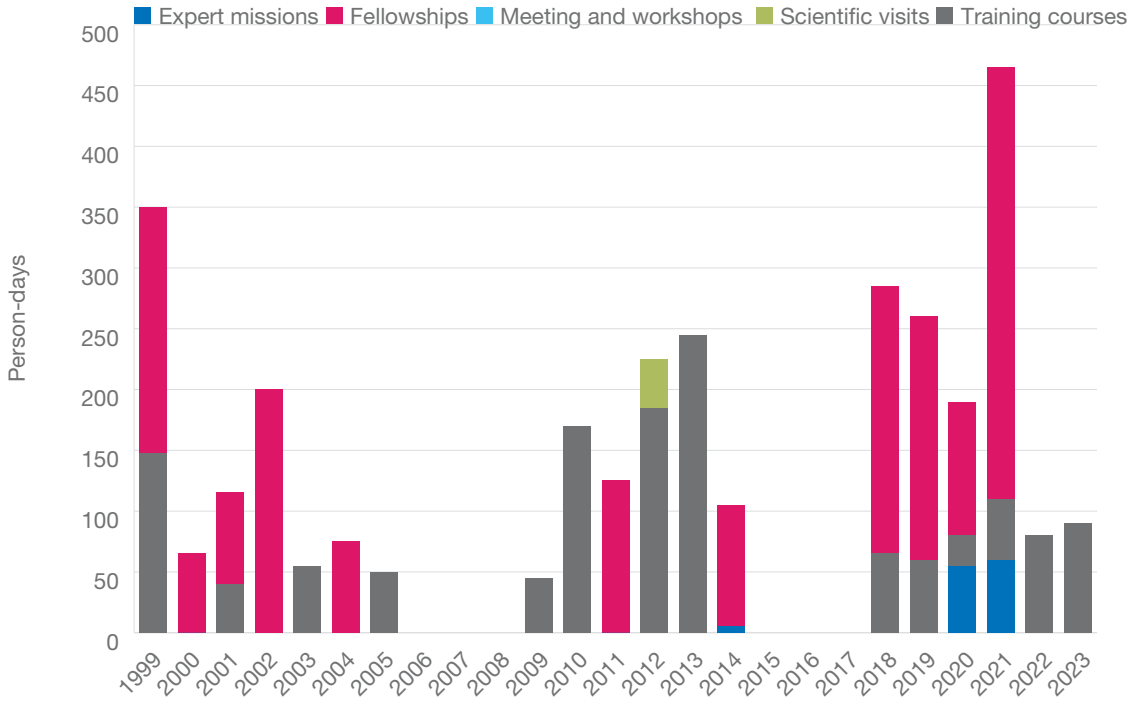
FIG. VII–13. Direct annual nominal funding provided by the IAEA for the food safety RCA activities being evaluated.



VII–4.2. Indirect costs associated with RCA activities

The opportunity costs of time for experts in RCA SPs to participate in the RCA activities being evaluated were estimated in proportion to person-days of involvement in these activities (Fig. VII–14). The cost of each person-day was based on GDP per capita in RCA SPs, multiplied by a premium for skilled labour based on wage data from the International Labor Organization. Nominal costs were converted to real 1999 Euro using the relevant GDP deflator for each country and the relevant exchange rate. Additional costs to host RCA activities were estimated based on information provided by the IAEA. Training courses were assumed to cost EUR 1600 per day (2023 values) and other activities were assumed to cost EUR 800 per day.

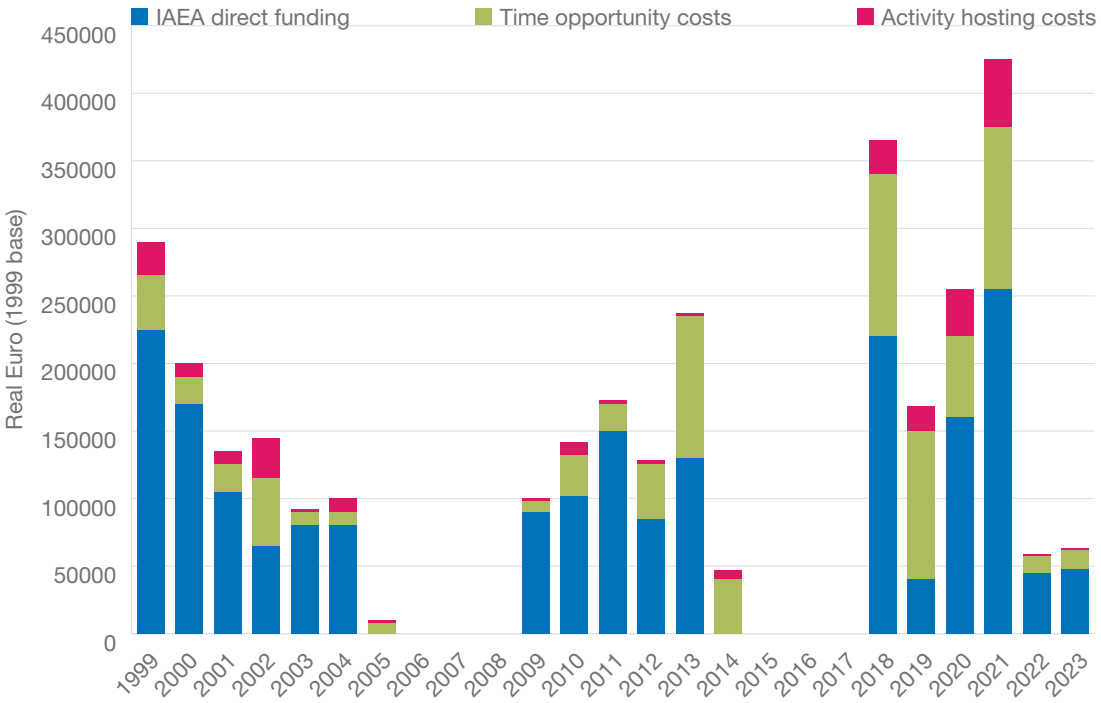
FIG. VII–14. Total involvement in food safety RCA activities.



VII–4.3. Total cost estimates

Figure VII–15 shows the estimates of real annual costs associated with RCA activities prior to the present value conversion, under baseline assumptions, following the estimation process described above. The present value of these costs is EUR 1.2 million (1999 base), over the evaluation period from 1999 to 2023.

FIG. VII–15. Baseline estimates of real costs of food safety RCA activities.



VII–5. Estimated net benefits enabled by food safety RCA activities

VII–5.1. Baseline results

In the baseline scenario, the present value of the estimated benefits enabled by the RCA activities is EUR 2.3 million and this exceeds the EUR 1.2 million present value of the costs of RCA activities (1999 base values). As explained above, these net benefits are estimated to be enabled by the RCA activities being evaluated but in practice require other complementary actions to achieve, such as political support, policy changes, investment in new technologies, changes to production processes and behavioural changes. It is therefore not possible to say that the RCA activities directly created these benefits.

There is substantial uncertainty associated with the numerical estimate of benefits as it is difficult to translate the available information about impacts of RCA activities into changes in costs of foodborne illnesses and food waste. Recognizing this, the approach to estimating RCA impacts was conservative, and sensitivity testing was done on key inputs and assumptions (see below).

There is additional evidence that the RCA activities being evaluated could have enabled economic impacts beyond those that were able to be quantified. As

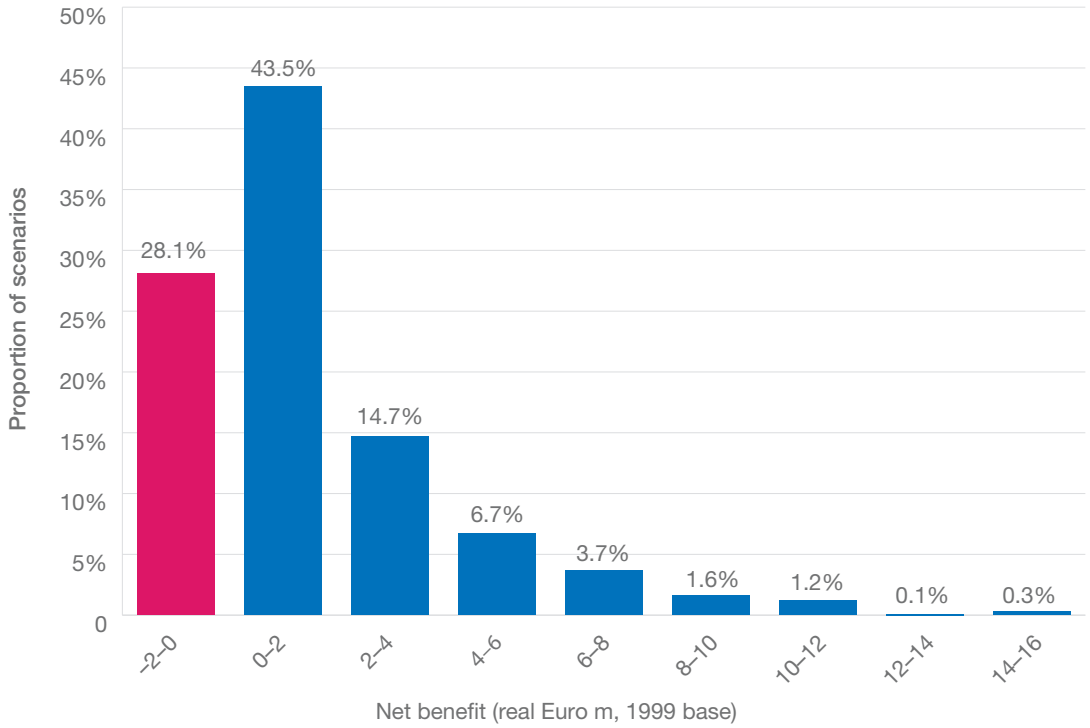
discussed above, irradiation could have supported additional exports of some food products, and origin authentication could promote or protect exports of geographically characteristic products.

VII–5.2. Sensitivity analysis

Results were generated for all combinations of low, baseline and high values of all parameters in the economic model, to test whether the findings are robust to alternative assumptions. Figure VII–16 summarizes the results of this analysis by showing the distribution of the estimated net benefit enabled by the RCA activities being evaluated, across sensitivity scenarios. The estimated net benefit is positive in around 72% of scenarios tested and negative in around 28% of scenarios.

Across most scenarios, the estimated net impacts are relatively small with net benefits less than EUR 10 million in around 70% of scenarios tested. This suggests it is likely that the RCA activities being evaluated enabled positive economic benefits but there are some scenarios with relatively pessimistic assumptions where this did not occur. As noted above, it was not possible to quantify all potential benefits of the RCA activities, and there is relatively limited data about potential impacts that could be quantified.

FIG. VII–16. Results of sensitivity scenario analysis.



VII–6. Summary of assumptions

Table VII–3 summarizes the assumptions used in the economic analysis, in addition to the assumptions of the RCA impact model that were summarized in Table VII–2. The basis for these assumptions is described in the relevant sections above.

Table VII–3. Summary of model parameter assumptions.

Parameter	Low	Baseline	High
Discount rate (real)	5.2%	10.2%	15.2%
Overhead costs proportion of total	5.0%	10.0%	20.0%
Proportion of food waste avoided due to irradiation	2.5%	5.0%	7.5%
Consumer proportion of food waste benefits	25.0%	50.0%	75.0%
Food irradiation volume uncertainty (relative to estimates)	75.0%	100.0%	125.0%

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Annex VIII: Methodology[1]

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The social and economic impact assessment methodology was developed specifically for conducting impact assessments case studies of Technical Cooperation (TC) projects under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA). The methodology follows the *Value for Investment* approach developed by Dr Julian King [VIII–2 – VIII–4] and the *Kinnect Group* approach to evaluation rubrics [VIII–5, VIII–6].

VIII–1. Evaluating impact in complex environments

From the outset, it was acknowledged that these case studies would be challenging to conduct. The RCA is a complex environment for evaluation. There are diverse countries and stakeholder groups, long term investments of decades, with contexts that are continuing to evolve, and multiple outcomes sought across a range of thematic areas. Impact evidence has not been routinely collected; TC outcome monitoring systems have generally focused on immediate outcomes and have not included longer-term social and economic impacts.

VIII–2. Developing the methodology

A methodology was needed that could:

- Evaluate impacts retrospectively, looking back many years.
- Evaluate long term effects because there is often a long lag between project completion and the realization of social and economic impacts.
- Capture unexpected outcomes, instead of just looking for the expected outcomes, because these can be as impactful as the project's originally stated target outcomes.
- Measure the intangible value of the RCA's contributions, such as networking, in addition to outcomes that are more amenable to numeric and/or monetary metrics.
- Deal with the complexity of attribution (or at least contribution), recognizing that one outcome can arise from many contributions (of which the RCA project may be only one), and conversely, one project could contribute to many different outcomes or impacts.

A meeting was held in Vienna, Austria, from 1–4 July 2019 to establish a methodology and work plan for performing the case studies. The meeting had eight participants, including representatives from TC Division for Asia Pacific (TCAP) and TC Division of Programme Support and Coordination (TCPC), and invited experts from China and New Zealand. Invited experts summarized and compared approaches and tools for social and economic impact assessment.

A methodology – Value for Investment – was proposed that combines strengths from the disciplines of economics and evaluation.

Evaluation is the systematic determination of the merit, worth or significance of something. Evaluation of social and economic impacts requires not only evidence of those impacts, but also valuing – interpreting the evidence through the lens of what matters to people [VIII–3]. Economics and evaluation bring different approaches to valuing. For example, cost-benefit analysis uses money as the metric for understanding value [VIII–7], while other approaches include numerical or qualitative synthesis [VIII–8] or citizen deliberation [VIII–9].

The Value for Investment approach combines approaches to valuing from evaluation and economics. It accommodates multiple values (e.g. social, cultural, environmental and economic) and multiple sources of evidence (qualitative and quantitative) to enable robust and transparent ratings of the RCA's impacts. The approach involves eight steps:

1. Understand the theory of change for the RCA food safety programme.
2. Develop performance criteria (i.e. (i) national personnel trained in all aspects of food irradiation and/or use of techniques for origin authentication, (ii) established infrastructure and improved national research and development (R&D) for food irradiation and origin authentication, (iii) raised awareness and understanding among governments, businesses and the public about the value of food irradiation and origin authentication, (iv) developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication, (v) enhanced and effective application of irradiation and nuclear technologies, including commercial treatment capacities for an expanding range of food products, (vi) economic benefits and (vii) health and environmental benefits).
3. Develop performance standards for each performance criterion (e.g. narratives that define excellent, good, etc.).
4. From the criteria and standards, select and identify the evidence needed.
5. Gather evidence using a mix of methods, including an online questionnaire deployed to all countries participating in relevant RCA projects, collated internal data held by IAEA, financial/cost data provided by IAEA, and narrative case examples provided by selected countries.
6. Analyze the evidence.
7. Synthesize and judge the evidence according to the agreed-upon definitions of good value (i.e. the performance criteria from Step 2 and the performance standards from Step 3).
8. Reporting based on the criteria and performance levels decided in advance.

VIII–3. Applying the methodology

VIII–3.1. Theory of change

A theory of change is a depiction of the programme to be evaluated, including the needs it is intended to meet and how it is intended to function [VIII–3]. A theory of change "explains how activities are understood to produce a series of results that contribute to achieving the final intended impacts" [VIII–10].

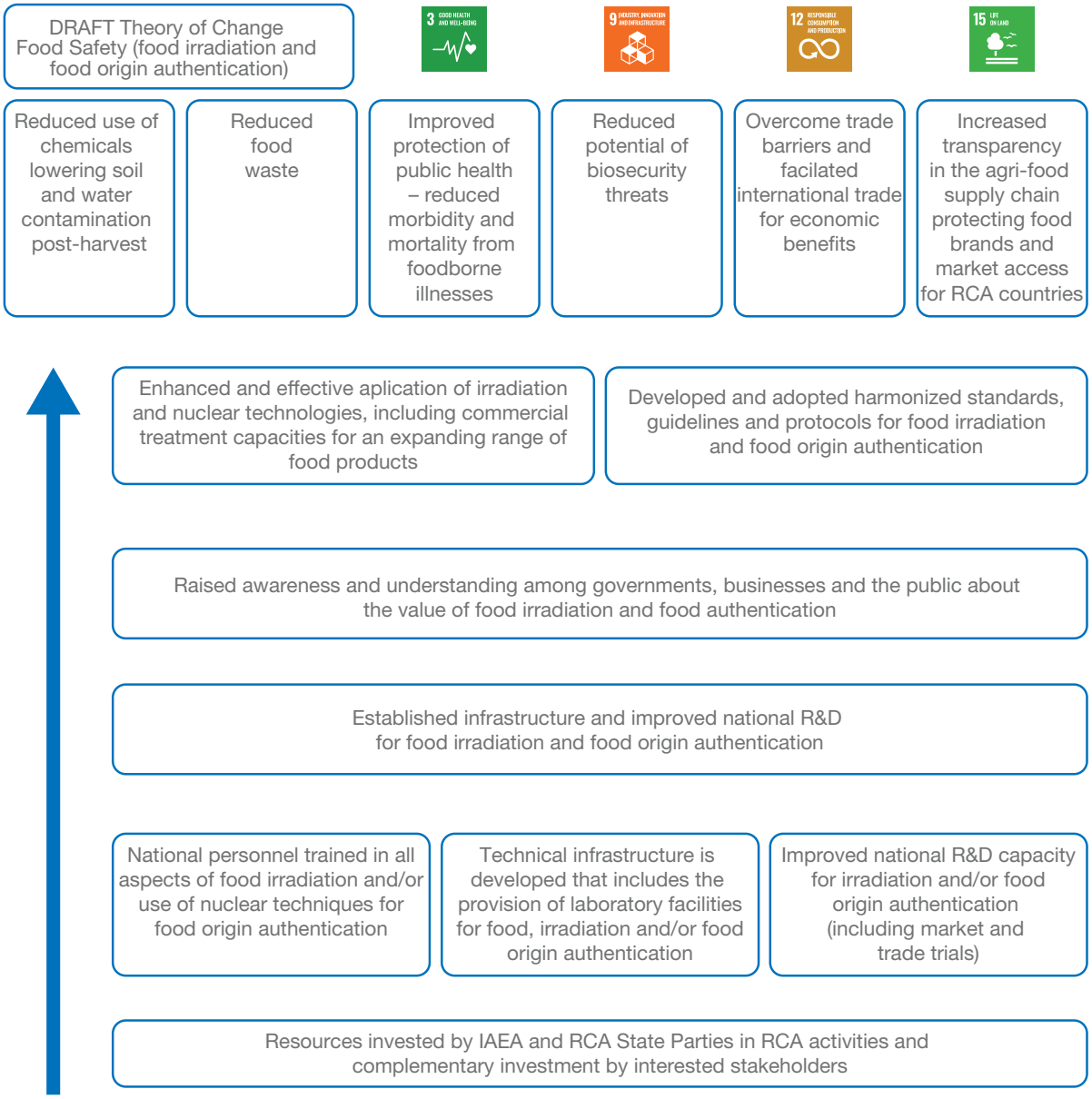
The theory of change for the food safety programme (Fig. VIII-1) was developed iteratively by the IAEA, selected experts from participating State Parties (SPs) and the impact assessment team. Developing a theory of change in a participatory manner helps lead to a clear and shared understanding of the programme [VIII–11].

A theory of change may be used as a tool when assessing causality or contribution [VIII–11]. In the case of food safety under the RCA, the focus was on the value added through regional collaboration. In the absence of a measurable counterfactual (e.g. a control group), the evaluation design theorized that regional collaboration would add value by establishing/developing technical infrastructure alongside ensuring there were national personnel trained in all aspects of food irradiation and origin authentication. The result of this would be greater awareness and understanding about the value of food irradiation and origin authentication, developed and adopted harmonized standards guidelines and protocols as well as enhanced and effective application of irradiation and nuclear technologies. It was further theorized that these impacts would provide benefits for people's health and the environment as well as economic benefits.

A theory of change can also be used to help identify a complete and coherent set of evaluation criteria [VIII–8]. For the food safety case study, it was agreed that the focus of the evaluation would be on seven impact areas:

- National personnel trained in all aspects of food irradiation and/or use of nuclear techniques for origin authentication improved national research and development (R&D) capacity for food safety;
- Established infrastructure and improved national R&D for food irradiation and food origin authentication;
- Raised awareness and understanding among governments, businesses and the public about the value of food irradiation and food origin authentication;
- Developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication;
- Enhanced and effective application of irradiation and nuclear technologies, including commercial treatment capacities for an expanding range of food products;
- Economic benefits enabled by the RCA;
- Health and environmental benefits.

FIG. VIII–1. Theory of change for the RCA food safety programme.



VIII–3.2. Criteria and standards

Evaluation criteria and standards for the four impact areas were collaboratively developed. Tables VIII–1–VIII–7 set out the *rubrics* (criteria and standards) used in this impact assessment. Each rubric corresponds to a selected impact area from the theory of change.

Table VIII–1. RUBRIC FOR CRITERION 1: National personnel trained in all aspects of food irradiation and/or use of nuclear technologies for origin authentication.

Standard (to be applied to each SP)	Criterion 1: National personnel trained in all aspects of food irradiation and/or use of nuclear techniques for origin authentication
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in the RCA programme of the IAEA results in: ▶ An increase in in-country personnel trained to carry out **all** aspects of food irradiation; **and** ▶ An increase in in-country personnel trained to use nuclear techniques for origin authentication
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in the RCA programme of IAEA results in: ▶ An increase in in-country personnel trained to carry out **all** aspects of food irradiation; **or** ▶ An increase in in-country personnel trained to use nuclear techniques for origin authentication
Adequate (meeting bottom-line expectations)	Participation in the RCA programme of IAEA results in an increase in in-country personnel trained to carry out **some** aspects of food irradiation
Minor (not meeting expectations)	Standard for adequate not met

Table VIII–2. RUBRIC FOR CRITERION 2: Established infrastructure and improved national R&D for food irradiation and food origin authentication.

Standard (to be applied to each SP)	Criterion 2: Established infrastructure and improved national R&D for food irradiation and food origin authentication
Excellent (exceeding expectations) Meets the standard for Good, plus:	As a result of RCA, there are: ▶ Research outputs and publications on food irradiation **and** food origin authentication (including market and trade trials); **and** ▶ Infrastructure for the provision of national and commercial laboratory facilities for food analysis and irradiation **and** food origin authentication
Good (meeting expectations) Meets the standard for Adequate, plus:	As a result of RCA, there are: ▶ Research outputs and publications on food irradiation **and** food origin authentication (including market and trade trials); **or** ▶ Infrastructure for the provision of laboratory facilities for food analysis and irradiation **and** food origin authentication
Adequate (meeting bottom-line expectations)	As a result of RCA, there are: ▶ Research outputs and publications on food irradiation **or** food origin authentication; **or** ▶ Infrastructure for the provision of laboratory facilities for food analysis and irradiation **or** food origin authentication
Minor (not meeting expectations)	Standard for adequate not met

Table VIII–3. RUBRIC FOR CRITERION 3: Raised awareness and understanding among governments, businesses and the public about the value of food irradiation and food origin authentication

Standard (to be applied to each SP)	Criterion 3: Raised awareness and understanding among governments, businesses and the public about the value of food irradiation and food origin authentication
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in RCA enables: ▶ An improvement in consumers' **acceptance** about the value of food irradiation and/or food origin authentication
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in RCA enables: ▶ An improvement in government's **knowledge** about the value of food irradiation and/or food origin authentication; **and** ▶ An improvement in businesses' **knowledge** about the value of food irradiation and/or food origin authentication; **and** ▶ An improvement in consumers' **knowledge** about the value of food irradiation and/or food origin authentication
Adequate (meeting bottom-line expectations)	Participation in RCA enables: ▶ An improvement in government's **knowledge** about the value of food irradiation and/or food origin authentication; **or** ▶ An improvement in businesses' **knowledge** about the value of food irradiation and/or food origin authentication
Minor (not meeting expectations)	Standard for adequate not met

Table VIII–4. RUBRIC FOR CRITERION 4: Developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication.

Standard (to be applied to each SP)	Criterion 4: Developed and adopted harmonized standards, guidelines and protocols for food irradiation and origin authentication
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in RCA enables a **significant** increase in: ▶ New regulations or changes to existing regulations and policies that support food irradiation ▶ Policy decisions and interventions related to food irradiation New guidelines and protocols or changes to guidelines and protocols for the use of origin authentication technology
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in RCA enables **some** increase in: ▶ New regulations or changes to existing regulations that support food irradiation ▶ Policy decisions and interventions related to food irradiation New guidelines and protocols or changes to guidelines and protocols for the use of origin authentication technology
Adequate (meeting bottom-line expectations)	Participation in RCA enables **any** increase in: ▶ New regulations or changes to existing regulations that support food irradiation ▶ Policy decisions and interventions related to food irradiation New guidelines and protocols or changes to guidelines and protocols for the use of origin authentication technology
Minor (not meeting expectations)	Standard for adequate not met

For the purposes of the impact assessment:

→ 'Significant increase' is an increase of sufficient magnitude to make a material difference to food safety;

→ 'Some increase' is a non-trivial increase, but not of sufficient magnitude to make a material difference to food safety;

→ 'Any increase' is a material increase greater than zero.

Table VIII–5. RUBRIC FOR CRITERION 5: Enhanced and effective application of irradiation and nuclear technologies, including commercial treatment capacities for an expanding range of food products.

Standard (to be applied to each SP)	Criterion 5: Enhanced and effective application of irradiation and nuclear technologies, including commercial treatment capacities for an expanding range of food products
Excellent (exceeding expectations) Meets the standard for Good, plus:	RCA enables: ▶ An expansion of the **commercial** use of food irradiation **and** food origin authentication
Good (meeting expectations) Meets the standard for Adequate, plus:	RCA enables: ▶ An expansion of the **commercial** use of food irradiation **or** food origin authentication
Adequate (meeting bottom-line expectations)	RCA enables an expansion of the use of irradiation to a wider range of food products
Minor (not meeting expectations)	No material increase **in any of:** new regulations or changes to existing regulations, policy decisions and interventions, levels of enforcement, number of pollutions programmes and evidence of population-level behaviour change

Table VIII–6. RUBRIC FOR CRITERION 6: Economic benefits enabled by the RCA.

Standard (to be applied to each SP)	Criterion 6: Economic benefits enabled by the RCA
Excellent (exceeding expectations) Meets the standard for Good, plus:	Economic analysis suggests with a high level of certainty that the investment created more value than it consumed. Break-even is likely in nearly all scenarios (even under conservative assumptions used in the sensitivity analysis).
Good (meeting expectations) Meets the standard for Adequate, plus:	Economic analysis suggests more likely than not, the investment created more value than it consumed. Break-even is likely in over half the range of scenarios (and under realistic mid-range assumptions used in the sensitivity analysis).
Adequate (meeting bottom-line expectations)	Economic analysis suggests that under some scenarios, the investment created more value than it consumed. Break-even is possible (under plausible assumptions used in the sensitivity analysis).
Minor (not meeting expectations)	Break-even is unlikely (or only possible under optimistic assumptions used in the sensitivity analysis).

Table VIII–7. RUBRIC FOR CRITERION 7: Health and environmental benefits.

Standard (to be applied to each SP)	Criterion 7: Health and environmental benefits
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in the RCA enables **significant:** ▶ Reduction in morbidity and mortality from foodborne illnesses Reduction in chemical use post-harvest, thereby lowering soil and water contamination ▶ Improvement in transparency in the agricultural-food supply chain
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in the RCA enables **some:** ▶ Reduction in morbidity and mortality from food-borne illnesses ▶ Reduction in chemical use post-harvest, thereby lowering soil and water contamination ▶ Improvement in transparency in the agricultural-food supply chain
Adequate (meeting bottom-line expectations)	Participation in the RCA enables **any:** ▶ Reduction in morbidity and mortality from food-borne illnesses ▶ Reduction in chemical use post-harvest, thereby lowering soil and water contamination ▶ Improvement in transparency in the agricultural-food supply chain
Minor (not meeting expectations)	Standard for adequate not met

VIII–3.3. Evidence for the assessment

The theory of change, criteria and standards provided important points of reference to identify what evidence is needed for the impact assessment. For this reason, selection of methods was undertaken after clarifying the theory of change, criteria and standards. This sequence of steps helps to ensure that the evidence is relevant and focuses on the right changes [VIII–4].

Examination of the rubrics above revealed that the social and economic impacts of the RCA are diverse, and a mix of quantitative, qualitative and economic evidence was needed for the impact assessment. For example, the economic value captured by a reduction in morbidity and mortality due to foodborne illness has a value that is possible to estimate. However, other benefits, such as strengthened raised awareness and understanding about the value of food irradiation and food origin authentication, are more difficult to value monetarily. The inclusion of multiple methods and data sources enabled the assessment of wider impacts and value shown in the theory of change.

Accordingly, the case study used a mix of methods, including:

→ An online questionnaire deployed to all countries in the RCA;
→ Analysis of administrative data on food safety programmes, provided by the IAEA;
→ Gathering additional information from food safety experts at the IAEA and RCA SPs;
→ Narrative case examples, written from details provided by selected countries on a selection of ‘success cases’ of food safety programmes;
→ Economic analysis of costs and benefits of food safety programmes under the RCA.

VIII–3.3.1. Online questionnaire

The online questionnaire was designed and piloted in July 2024 and deployed between August and October 2024. The survey was structured in alignment with the rubrics to capture evidence needed in the six impact areas. It included a mix of quantitative (numeric or categorical) and qualitative (free-text) fields. The survey was administered electronically. Respondents entered data into a secure online form with automatic data validation. Responses were automatically compiled into a database for analysis.

Communication with countries about the online survey was led by the IAEA and included communication prior to deployment (to forewarn senior country representatives of the purpose and timing of the survey, giving them time to nominate a staff member responsible for completing the survey and set aside time for this task) and during deployment (including reminders, follow-up questions when needed to clarify responses and thanking country representatives for their close and effective cooperation). The communication and coordination from the IAEA and the RCA State Party National Representatives and their national experts were critical to the success of the survey.

VIII–3.3.2. Case examples

Development of the case examples occurred following survey data collection. The selection of case examples was agreed on by the IAEA. The senior contact person from each of the selected countries was contacted by IAEA to invite their participation.

Templates and instructions were developed for the countries preparing case examples and were sent to the nominated contact people. After receipt of the case example data, follow up contact was made with the contact people as required to clarify details. Narrative summaries were prepared.

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ABBREVIATIONS

EA-IRMS	elemental analysis-isotope ratio mass spectrometry
FS	food safety
FTIR	Fourier transform infrared spectroscopy
GP	Government Party
ICP-MS	inductively coupled plasma mass spectrometry
ICP-OES	inductively coupled plasma optical emission spectrometry
IRMS	isotope ratio mass spectrometry
RCA	Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific
SP	State Party
TC	IAEA Technical Cooperation
TCAP	TC Division for Asia Pacific
TCPC	TC Division of Programme Support and Coordination

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This report evaluates the social and economic impacts of food safety programmes implemented from 2020 to 2024, supported by the IAEA under the Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA). It is one of four thematic assessments examining the application of nuclear science and technology in air quality monitoring, food safety, isotope hydrology and nuclear medicine.

Drawing on evidence from 19 participating State Parties, IAEA administrative data, expert analysis, five success case stories and a comprehensive cost-benefit assessment, the report illustrates how technical cooperation in food safety has advanced sustainable development across Asia and the Pacific.

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