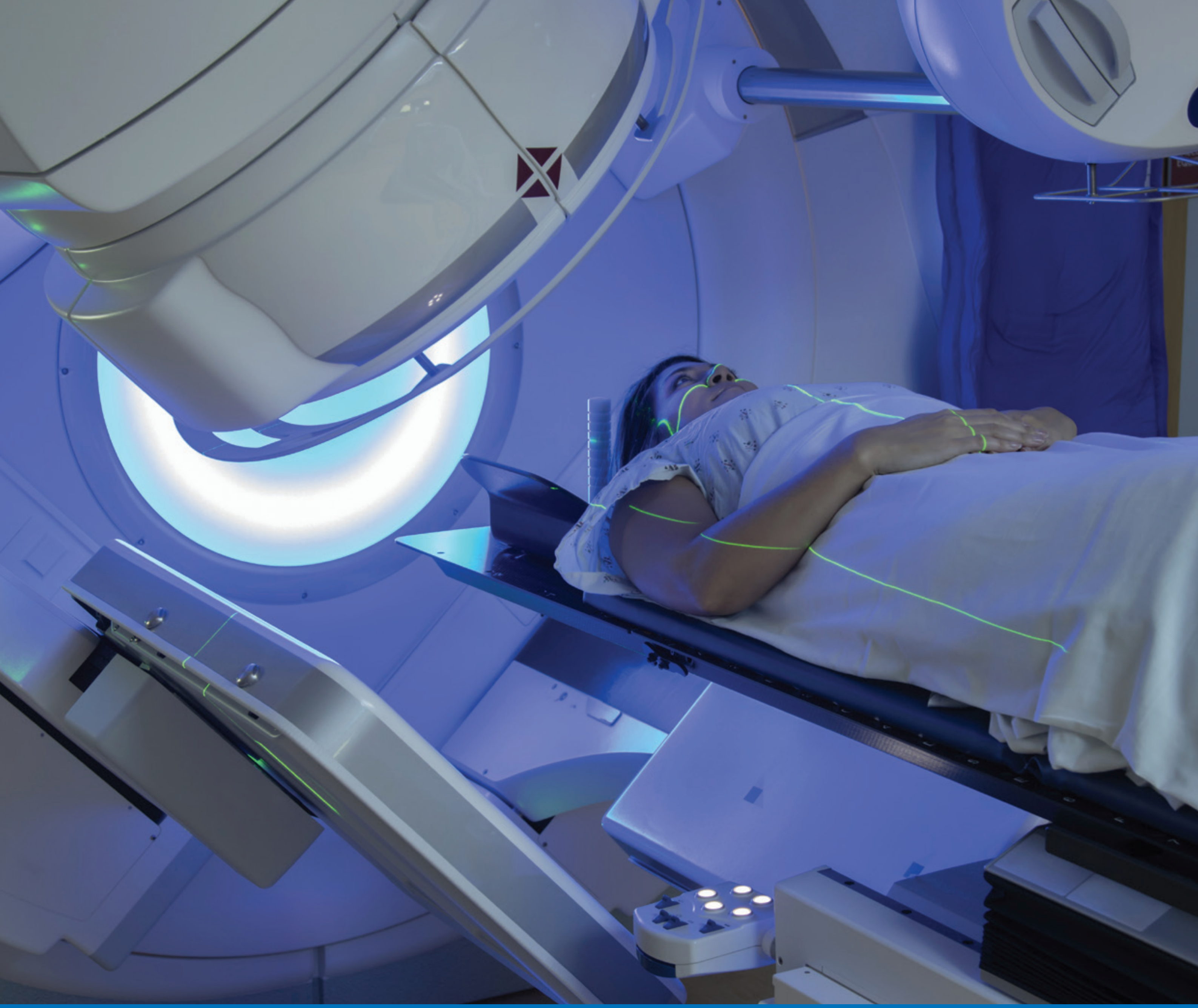

Social and Economic Impact Assessment of the RCA Programme

Radiotherapy Case Study

IAEA | Technical Cooperation Programme

RCA

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Contents

Tables

Figures

Acronyms

Name	Acronym
3-dimensional Conformal Radiation Therapy	3D-CRT
3-dimensional Image-Guided Brachytherapy	3D-IGBT
Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific	RCA
Educational/Training Programmes	ET
IAEA Technical Cooperation Programme	TCP
Intensity-Modulated Radiation Therapy	IMRT
International Atomic Energy Agency	IAEA
Member States	MS
Radiation Oncology	RO
Radiotherapy	RT
Stereotactic Body Radiation Therapy	SBRT

Executive Summary

The Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA) will celebrate its 50th Anniversary in 2022. This report assesses the social and economic impacts of radiotherapy projects under the RCA, focusing on value added over and above the primary research that has been undertaken by individual countries independently.

Radiotherapy is one of the most widely used therapies for cancer treatment. To build and enhance capacity in radiotherapy in RCA State Parties, regional training courses, workshops, expert missions, and basic equipment in relation to radiotherapy techniques have been provided through RCA radiotherapy projects.

By 2020, our economic modelling estimates that 47 000 health-adjusted life years had been gained cumulatively by cancer patients in RCA State Parties from additional radiotherapy treatment attributable to the RCA.

This impact assessment was designed and undertaken by a team of external experts, in consultation with IAEA and RCA stakeholders.[1] It involved gathering evidence through an online questionnaire completed by 21 of the 22 participating State Parties, analysis of IAEA administrative data, gathering information from radiotherapy experts at the IAEA and State Parties, narrative success cases of radiotherapy projects from four State Parties, and economic analysis of costs and benefits of radiotherapy projects under the RCA.

The impact assessment found that the RCA has supported State Parties to strengthen their radiotherapy workforces and increase access to quality radiotherapy. These impacts have in turn contributed to increases in life span, quality of life, and economic benefits. Specifically, participation in the RCA over the last 20 years has enabled State Parties to:

- Offer **116** educational training programmes in radiotherapy
- Establish **3 215** radiation oncology departments and **94** radiation oncology societies (33 national and 61 subnational)
- Grow the radiotherapy specialist workforce by **232 per cent** including Radiation Oncologists, Medical Physicists, Radiation Technology Therapists, and Radiation Oncology Nurses
- Increase operational radiotherapy equipment and technology (linear accelerators and Cobalt-60 machines) by **129 per cent**
- Increase the quality of treatment, and increase the number of cancer patients using domestic radiotherapy facilities by **121 per cent**
- Improve local tumour control rates from 39 per cent in 2000 to **55 per cent** in 2020
- Improve cancer survival rates from 41 per cent in 2000 to **55 per cent** in 2020.[2]

These impacts may not be solely attributable to the RCA, but the RCA contributed significantly to these impacts, according to the majority of State Parties. Feedback from many countries highlighted the importance of the RCA for building their radiotherapy skills and capacity.

By 2020, our economic modelling estimates that **47 000** health-adjusted life years

1 The project was commissioned by the IAEA Technical Cooperation Division for Asia-Pacific (TCAP) and TC Division of Programme Support and Coordination (TCPC). Invited experts from the RCA provided advice and support. Please refer to the Acknowledgements for significant contributors.

2 Limitations: Since countries involved in the analysis are diverse in size and scale of the RT programme, increases measured and expressed at regional level may be skewed to a few countries (in particular large ones). Indicators such as survival rates and control rates are cancer-specific and heavily dependent on screening and early diagnosis in addition to treatment. Figures reported reflect estimates provided by State Parties.

had been gained cumulatively by cancer patients in RCA State Parties from additional radiotherapy treatment attributable to the RCA. Taking account of the costs of the RCA itself, the operating and capital costs of additional radiotherapy treatment attributable to the RCA, and the overall effectiveness of radiotherapy as a treatment for cancer, we estimate the cost-effectiveness of the RCA at approximately EUR 26 000 per additional health-adjusted life year gained. This is comparable to the cost-effectiveness of other mainstream cancer treatments, and is also comparable to the average estimated willingness to pay for additional health-adjusted life-years across RCA State Parties.

Cost-benefit analysis estimated that incremental improvements in radiotherapy in State Parties under the RCA created more economic value than it consumed. We estimate that each EUR 1 of costs directly or indirectly attributable to RCA activities between 2000 and 2020 was associated with **EUR 1.3** of social and economic benefits on average in our baseline scenario when accounting for the broader wellbeing benefits associated with improved survival rates for cancer patients attributable to the RCA. Sensitivity analysis found that the net benefits attributable to the RCA remained positive under most alternative assumptions about benefits and costs, with a likely range of benefits between 0.7 EUR and 2.1 EUR per 1 EUR of costs. This suggests it is likely that the economic benefits of the RCA exceeded its costs.[3]

Pre-defined performance criteria were agreed with IAEA and State Party experts to provide an evaluative framework for the impact assessment (Tables 12–14, Annex G). On the basis of evidence provided by the IAEA and State Parties, the RCA's impacts meet standards for **good performance** on all criteria, including strengthened radiotherapy workforce; increased access to quality radiotherapy; increased life span and quality of life; and economic benefits.

each EUR 1 of costs directly or indirectly attributable to RCA activities between 2000 and 2020 was associated with EUR 1.3 of social and economic benefits on average

3 These results are averages for the period 2000-2020 and should not be used to make decisions about the future of the RCA or to decide whether the scale of the RCA should be increased or decreased.

Introduction

The International Atomic Energy Agency (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 (UN) Sustainable Development Goals. The IAEA works in close partnership with Member States, UN agencies, research organisations and civil society to maximise the contribution of nuclear science and technology to the achievement of 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) was established in 1972 and has enjoyed the benefit of the IAEA Technical Cooperation (TC) programme since. With the RCA due to celebrate its 50th Anniversary in 2022, it is timely to assess the social and economic impacts of the RCA supported under the IAEA TC programme.

22 **The RCA has 22 participating State Parties**

Australia	**Laos**	**Philippines**
Bangladesh	**Malaysia**	**Singapore**
Cambodia	**Mongolia**	**South Korea**
China	**Myanmar**	**Sri Lanka**
Fiji	**Nepal**	**Thailand**
India	**New Zealand**	**Vietnam**
Indonesia	**Pakistan**	
Japan	**Palau**	

At the 48th RCA General Conference Meeting in Vienna, Austria, 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 to undertake case studies. A methodology was developed and was piloted to assess social and economic impacts of RCA projects. This report presents the findings from the social and economic impact assessment of radiotherapy collaborations under the RCA.

Radiotherapy

Radiotherapy (also called radiation therapy) is one of the most widely used therapies for cancer treatment. It uses radiation to kill cancer cells or slow their growth by damaging their DNA. Radiotherapy can be used as treatment (in some cases to cure cancer, in others to prevent it from returning or inhibit its growth) and palliatively (to reduce pain and other symptoms). Radiotherapy is often used in conjunction with other cancer treatments such as surgery, chemotherapy and/or immunotherapy.

To build and enhance capacity in radiotherapy in RCA State Parties, regional training courses, workshops, expert missions, and basic equipment in relation to radiotherapy techniques have been provided through RCA radiotherapy projects. As a result, State Parties understand, absorb, receive, apply and/or develop radiotherapy techniques for cancer treatment in their country. RCA projects help State Parties to establish/upgrade radiotherapy centres and equipment, build capacity, educate, and train professionals working in radiotherapy technologies. The RCA also produces reference documents to help medical experts to use current and future advanced radiotherapy technologies in an effective and efficient manner. More cancer patients can receive quality cancer therapy services.

Social and economic impact assessment methods

The social and economic impact assessment methodology was developed specifically for the IAEA, in order to conduct impact assessments for case studies of TC projects under the RCA. The methodology follows the *Value for Investment* approach (King, 2017; King, 2019; King & OPM, 2018) and the Kinnect Group approach to evaluation rubrics (King *et al.,* 2013; McKegg *et al.,* 2018) – combining evidence from quantitative, qualitative, and economic analysis, through the lens of an agreed performance framework, to evaluate the impact of radiotherapy projects under the RCA.

Social and economic impacts of the radiotherapy projects are diverse and include contributing to a chain of impacts (see theory of change, Annex G) that includes:

- Training, education, professional development, and certification of the radiation oncology workforce *and*
- Establishing professional networks and societies, *leading* to
- Increasing the adoption and use of radiotherapy technology
- Increasing patient access to quality radiotherapy
- Increasing lifespan and quality of life.

The radiotherapy 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 21 of the 22 State Parties
- Analysis of administrative data on radiotherapy activity and costs, provided by IAEA
- Gathering additional information from radiotherapy experts at the IAEA and State Parties
- Narrative case examples, written from details provided by four countries on a selection of 'success cases' of radiotherapy projects
- Economic analysis of costs and benefits of radiotherapy projects under the RCA.

To combine the quantitative, qualitative and economic analysis, evaluation rubrics were developed. 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 the radiotherapy projects under the RCA from the mix of evidence. Refer to Annex G for full details of the methodology.

Social and economic impacts

The RCA has successfully supported participating State Parties in the Asia and the Pacific region to undertake a considerable body of work to increase radiotherapy capacity and use. This impact assessment focuses on the most recent two decades, since the year 2000. It focuses on the value added by the RCA, over and above the improvements that may have occurred within the individual countries if the RCA did not exist.

Key impacts of the RCA include increasing life span and quality of life, and associated economic value, through strengthening the radiotherapy workforce and increasing access to quality radiotherapy. The impacts are summarised in this section and detailed in a series of Annexes.[4]

A total of 22 State Parties participate in the RCA. Of these, 18 received support to improve capacity, capability and access to quality radiotherapy. Four State Parties (Australia, Japan, New Zealand, and since 2010 South Korea) volunteered to work as resource countries to provide support for the RCA. The following analysis focuses on the 19 State Parties (including South Korea) that have received support through the programme.

Strengthened radiotherapy workforce

The RCA has supported State Parties to grow and strengthen the radiotherapy workforce. These impacts include enabling State Parties to:

- Offer educational training programmes
- Establish radiation oncology departments and societies
- Grow the workforce of radiotherapy specialists.

In 2020, across all the State Parties to the RCA, there were a total of:

- **116** educational programmes in radiotherapy available
- **3 215** radiation oncology departments
- **94** radiation oncology societies.

From the 17 State Parties for which an educational programme is available, 15 (88 per cent) reported that the RCA's support contributed to their establishment.

Between 2000 and 2020, the radiotherapy workforce in the State Parties grew by **232 per cent** to a total of 46 862 specialists, including:

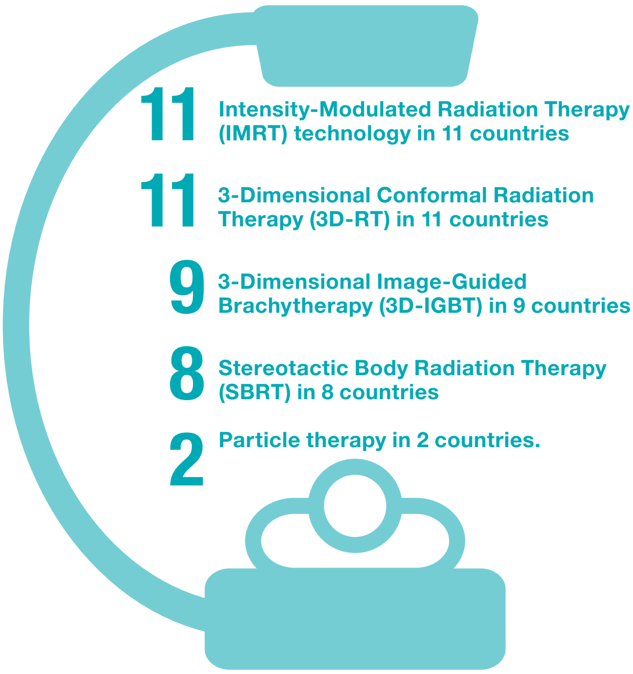
- **16 628** additional radiation oncologists
- **14 260** additional radiation technology therapists
- **9 244** additional radiation oncology nurses
- **6 730** additional medical physicists.

Approximately three quarters of the radiotherapy workforce (75.7 per cent) were certified specialists in 2020. Of the 19 countries (including South Korea) that received support through the RCA, 17 (89 per cent) considered that the RCA contributed to the increase in certified radiotherapy specialists between 2000–2020.

4 For additional detail on these impacts, refer to Annexes A-D (case examples: Bangladesh, Indonesia, Mongolia, Thailand), Annex E (survey results) and Annex F (economic analysis).

One example of the RCA's impact on the radiotherapy workforce can be seen in Bangladesh. Since joining the RCA in 2011, Bangladesh has received continuous technical support for building the skills of its radiotherapy workforce as well as to support the expansion and strengthening of radiotherapy facilities. More than 20 advanced training courses were delivered under the framework of national and regional technical cooperation projects. As a result, a cohort of radiation oncologists, radiation technology therapists and medical physicists improved their knowledge and skills on site-specific radiotherapy for common cancers. Between 2000 and 2020, Bangladesh has increased its radiotherapy workforce by over **200 per cent.**

The RCA also contributed to the introduction of:



Increased access to quality radiotherapy

Under the RCA, State Parties have successfully increased access to quality radiotherapy. Impacts include enabling State Parties to:

- Increase operational radiotherapy equipment and technology
- Reduce waiting times from diagnosis to admission for treatment
- Increase the number of cancer patients using domestic radiotherapy facilities and the quality of treatment.

From 2000 to 2020, there was a **129 per cent increase** in the number of operational radiotherapy machines (linear accelerators and Cobalt-60 machines) in RCA State Parties, from 2 009 to 4 500 machines. Of the 19 recipient State Parties, six (32 per cent) reported that being part of the RCA contributed to their country investing in additional radiotherapy equipment.

Of the 19 recipient State Parties, 16 (84 per cent) reported that the quality of radiotherapy services improved as a result of participating in the RCA.

The number of cancer diagnoses has increased since 2000. As a result of the increased access to quality radiotherapy, **121 per cent** more patients were treated using domestic radiotherapy facilities in 2020 than in 2000 (Figure 1).

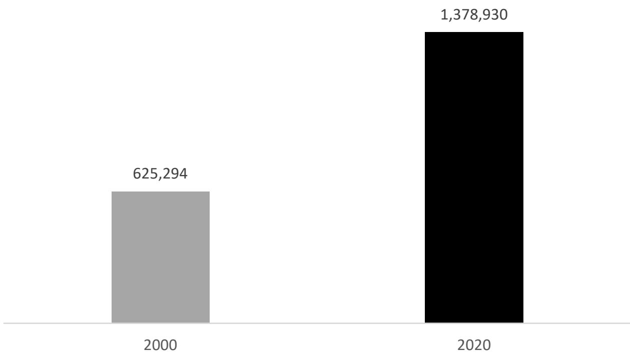


Figure 1: Patients treated using domestic radiotherapy facilities 2000 and 2020

Waiting times to receive radiotherapy treatment also reduced. The percentage of patients experiencing a waiting time of less than 10 days improved from 59 per cent to 61 per cent.

Indonesia provides an example of increased access to quality radiotherapy under the RCA. Indonesia has reported a **300 per cent** increase in radiotherapy equipment, with a total of 81 machines installed across 47 radiotherapy centres by 2020. The RCA has supported the establishment of IMRT, 3D-CRT, and 3D-IGBT technologies, as well as the establishment of a teleradiotherapy network, so that eight medical centres can now share diagnostic and radiotherapy plan information with the main Cipto Mangunkusumo Hospital in Jakarta. This improves the quality of radiotherapy treatment in locations situated far from urban centres – especially important given that Indonesia is the largest archipelago country in the world, with 50 per cent of the population living further than 100km from radiotherapy equipment. Indonesia has seen over **300 per cent** growth in cancer patients treated using domestic radiotherapy facilities, and significant improvements in wait times. The proportion of patients with a wait time of less than 10 days to receive radiotherapy treatment has improved from 50 per cent to 80 per cent.

Increased life span and quality of life

As a result of the strengthened radiotherapy workforce and increased access to quality radiotherapy, State Parties have been able to achieve increases in life span and quality of life for cancer patients, including:

- Increased local tumour control rates[5]
- Increased survival rates.[6]

As shown in Figure 2, the approximate average of the 5-year local tumour control rates estimated by State Parties improved from 39 per cent in 2000 to **55 per cent** in 2020. Of the 15 State Parties that reported an increase in the 5-year control rate, 14 (93 per cent) considered that the RCA had contributed to this result.

From 2000 to 2020, the approximate average 5-year survival rate across all types of cancer increased from 38 per cent in 2000 to **51 per cent** in 2020.[7] Of the 15 State Parties that reported an increase in the 5-year survival rate, 13 (87 per cent) considered that the RCA had contributed to this result.

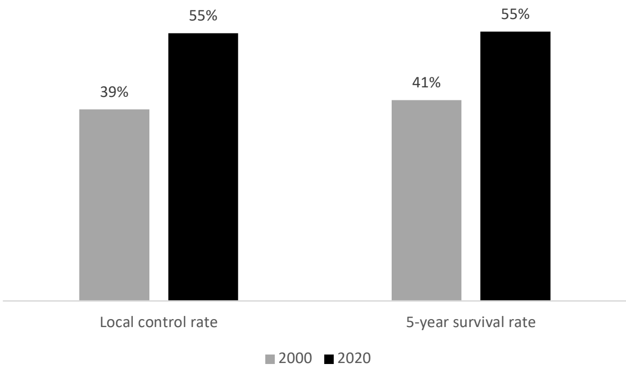


Figure 2: Average improved cancer outcomes in Member States, 2000 to 2020

5 5-year local control rate is the proportion of patients that retain the status of clear tumour clearance in the primary site after five years, as a percentage of all patients in the relevant patient population.

6 5-year survival rate is the proportion of patients surviving after five years, as a percentage of all patients in the relevant patient population.

7 Limitations: Since countries involved in the analysis are diverse in size and scale of the RT programme, increases measured and expressed at regional level may be skewed to a few countries (in particular large ones). Indicators such as survival rates and control rates are cancer-specific and heavily dependent on screening and early diagnosis in addition to treatment. Figures reported reflect estimates provided by State Parties.

For example, in Thailand, improvements in access to quality radiotherapy have enabled significant increases in the number of patients accessing radiotherapy, and reduction in wait times. The adoption of improved radiotherapy technology has also led to an improvement in the quality of treatment for cancer patients in the country. These developments have contributed to significantly improved treatment outcomes for people with cancer, including the local control rate (60 per cent in 2020, up from 40 per cent in 2000) and the five-year survival rate (65 per cent, up from 45 per cent).

The impact of the RCA on survival and quality of life cannot be measured directly. However, we estimate that by 2020, approximately **47 000** health-adjusted life years had been gained cumulatively by cancer patients in member states from additional radiotherapy treatment attributable to the RCA.[8]

Economic benefits

A social cost-benefit analysis was conducted to estimate economic impacts generated by the RCA. The analysis estimated the incremental (additional) costs and benefits that are attributable to RCA collaboration in radiotherapy – i.e. it did not estimate the benefits and costs of radiotherapy activities as a whole but rather the benefits and costs associated with collaboration under the RCA, compared to a hypothetical situation with no RCA.

The analysis used data from the survey, together with administrative and cost data provided by the IAEA, and public data from other sources such as the World Health Organisation. It estimated the costs and benefits that could be attributed to the RCA between 2000 to 2020. Costs and benefits were analysed as annual time series and adjusted for timing, using discounting to convert values occurring at different points in time into present values.

Benefits were first estimated as additional health-adjusted life years gained through better access to quality radiotherapy, attributable to the RCA. The gain in health-adjusted life years was then converted to monetary values using three alternative methods, focused on pure economic benefits, local social benefits, and international social benefits respectively.[9]

Costs represent the opportunity costs arising from committing resources of the IAEA and State Parties to RCA-related activities. They include direct costs associated with RCA activities, in-kind (non-monetary) contributions of State Parties to RCA activities, and operating and capital costs associated with expanded radiotherapy treatment activities in State Parties that are attributable to the RCA.

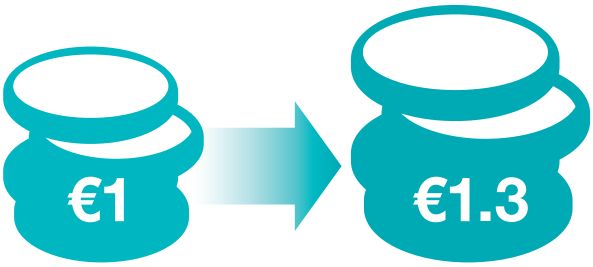
Results of the analysis indicate that the RCA delivered good economic value. Each additional health-adjusted life-year attributable to increased access to quality radiotherapy enabled by the RCA was achieved at a cost of EUR 26 000 on average.[10] This estimate reflects the costs of RCA activities, the

8 See economic analysis (Annex F) for details.

9 The pure economic benefits method values each additional life-year at GDP per capita in the relevant country. The local social benefits method values life years at a multiple of GDP (2.4x in the base case) reflecting the additional social and wellbeing benefits associated with additional life years. The international social benefits method uses a constant willingness to pay for additional life years across all countries (EUR 27 000 in the base case). The reasons for these alternative approaches are explained in Annex F below.

10 In our model, the assumed operating cost per radiotherapy treatment session ranges from EUR 59 in lower-middle income countries to EUR 212 in higher income countries, based on values from the literature. At a country level, the overall average cost of treating a patient with radiotherapy depends on the mix of types of cancers in that country. The estimated operating cost per patient treated in our model ranges from around EUR 1 100 per patient in lower-middle income countries to EUR 4 236 in high income countries. The estimated cost-effectiveness of the RCA of EUR 26 000 per additional life-year reflects these treatment costs plus other costs associated with the RCA, combined with the effectiveness of radiotherapy at generating benefits in terms of additional life years for patients treated. These assumptions are explained in more detail in Annex F.

operating and capital costs of additional radiotherapy treatments attributable to the RCA, and the effectiveness of radiotherapy as a treatment for cancer. This shows that the RCA is cost-effective and generates incremental benefits in proportion to costs that are comparable to mainstream cancer treatments. If benefits are valued in monetary terms, **for each EUR 1 of costs, we estimate that benefits of EUR 1.3 were generated under the local social benefits method.**



As is often the case in cost-benefit analysis, some important parameters required modelling assumptions to be developed, in consultation with radiotherapy experts. To understand the implications of uncertainty in these modelling assumptions, sensitivity analysis was conducted that involved testing how the estimates of costs and benefits varied under alternative assumptions, including assumptions about the extent to which improvements in radiotherapy treatment in RCA State Parties can be attributed to RCA activities. Sensitivity analysis revealed that under a range of alternative assumptions, **net local social benefits could be between EUR 0.7 and EUR 2.1.** The ratio of benefits to costs was greater than 1 (i.e. break even was achieved) in 77 per cent of scenarios.

These estimates are conservative because they do not include additional health-adjusted life-years gained after 2020 and attributable to the investment up to 2020, benefits from improved quality of radiotherapy treatment facilitated through the RCA, or benefits to cancer patients from local control of tumours and/or palliative care that did not lead to improved five-year survival rates. In our assessment, the investment in the radiotherapy RCA by IAEA and State Parties more likely than not generated more value than it consumed.

These estimates of costs and benefits are retrospective and are based on actual outcomes under the RCA between 2000 and 2020. These results should not be used to make decisions about the future of the RCA, or to decide whether the scale of the RCA should be increased or decreased. Full details of the cost-benefit analysis are provided in Annex F.

Conclusion

The RCA has supported significant gains in strengthening the radiotherapy workforce and increasing access to quality radiotherapy. Significant social value has been achieved through increases in life span and quality of life for cancer patients.

Cost-benefit analysis estimated that the RCA created more economic value than it consumed between 2000 and 2020, with each EUR 1 of costs incurred between 2000 and 2019 associated with EUR 1.3 of economic benefits on average.

Pre-defined performance criteria were agreed with IAEA and State Party experts to provide an evaluative framework for the impact assessment (Tables 12–14, Annex G). Overall, the evidence of RCA impacts provided by the IAEA and State Parties indicates that the RCA meets agreed standards for **good performance** in achieving its intended impacts, across all four impact domains: strengthened radiotherapy workforce; increased access to quality radiotherapy; increased life span and quality of life and economic benefits.

Annex A: Radiotherapy treatment under RCA in Bangladesh – case example

Background

Although the use of radiation technology in the medical sector started in Bangladesh in the 1920s, it was limited only to diagnostic radiology.[11] It was not until the early 1950s, that the first Deep X-Ray teletherapy machine, aimed to treat localized solid tumours, was installed at a Bangladesh private hospital. In 1962, the Dhaka Medical College was the first public hospital to incorporate one of these machines within its facilities. Almost twenty years later, in 1981, the National Institute of Cancer Research and Hospital (NICRH) was founded by the Rotary Club of Dhaka as Rotary Cancer Detection Centre. The centre, which is the only tertiary care-cancer centre of the country, was handed to the national government in 1986.

In the first decades applying radiation technology for cancer treatment, the main treatment used was the conventional 2-dimensional treatment planning and delivery (2-D radiotherapy). This was because this form of treatment could be applied with reasonably simple equipment, infrastructure, and training. In the early 2000s, the country began making advances both in terms of radiotherapy equipment and human resources; the first linear accelerators (LINAC) were installed, and a group of Radiation Oncologists and Medical Physicists began receiving radiotherapy training in neighbouring countries through their own institutional training initiatives.

Despite these significant advances, the real milestone in the development of the field of radiotherapy treatment for cancer patients was reached in 2011, when Bangladesh joined the radiotherapy programme under the RCA.[12] Through its participation in the RCA, Bangladesh has received continuous technical assistance for the skills upgrade of its radiotherapy specialists, as well as support for the expansion and strengthening of its radiotherapy facilities. This has helped the country to transition from 2-D radiotherapy to 3-dimensional conformal radiotherapy (3-D CRT) treatment, improving the effectiveness of treatment while reducing toxicities for cancer patients in the country.

Strengthening of radiotherapy workforce

Because training radiotherapy specialists is essential to guaranteeing the quality of radiotherapy treatment, capacity building in radiation oncology became one of the key contributions of the RCA radiotherapy programme in Bangladesh. More than 20 advanced training courses were delivered under the framework of both national and regional technical cooperation projects (including RCA and other projects)[13], in the topics of 3-D CRT, Stereotactic Body Radiation Therapy, and Intensity Modulated Radiation Therapy.

As a result, a cohort of Radiation Oncologists, Medical Physicists, and Radiation Technology Therapists from both the public and private sectors improved their knowledge and skills on site specific radiotherapy for common cancers. Indeed, between 2000 and 2020, the number of certified Radiation Oncologists and Medical Physicists increased from 97 to 180, and from 3 to 25, respectively. While there were only 20 certified Radiation Technology Therapists in the country in 2000, that number reached 200 in 2020.

11 Use of low doses of radiation to obtain highly detailed images of the inside of the human body for diagnostic purposes.

12 Under the first radiotherapy project, RAS6053 'Improving Image Based Radiation Therapy for Common Cancers in the RCA region'.

13 For example, BGD6026 'Building Capacity for Improved Cancer Management through Strengthening Human Resources in the Field of Radiation Oncology', RAS6085 'Enhancing Stereotactic Body Radiation Therapy for Frequent Cancers in the RCA region', and RAS6072 'Strengthening Intensity Modulated Radiation Therapy capability in the RCA region.'

Workshop for Radiation Oncologists: target volume definition treatment planning and evaluation. Source: Dhaka Medical College and Hospital

Adoption of radiotherapy technology

In addition to the training of specialists, the availability of sufficient and functioning radiotherapy technology is a necessary prerequisite for quality cancer treatment. With a population of 166 million, Bangladesh has 19 radiotherapy centres across the public and private sectors. Out of those, almost 50 per cent are situated in the capital of the country. A total of 42 radiotherapy machines are operational: 29 teletherapy and 13 brachytherapy units.

Although the number of radiotherapy machines is still below the target of one radiotherapy machine per million people recommended by the World Health Organization (WHO), there has been a vast improvement since 2000, when the country only had 8 operational radiotherapy equipment units.

the number of cancer patients treated with radiotherapy technology went from 3 000 in 2000, to 70 000 in 2020

Social and economic effects

Due to the increased number of well-trained medical staff, and radiotherapy facilities and equipment, accessibility to radiotherapy treatment for cancer patients has improved in the last decades: the number of cancer patients treated with radiotherapy technology went from 3 000 in 2000, to 70 000 in 2020.

In addition to accessibility, the quality of radiotherapy treatment has also improved with the adoption of modern technology. The country has transitioned from 2-D radiotherapy to 3-D CRT treatment. This allows larger doses of radiation to be applied more precisely to tumours, increasing the effectiveness of the treatment while at the same time reducing its toxicity. It is estimated that this has contributed to an increase of the average 5-year control rate from 25 per cent to 40 per cent and an increase of the average 5-year survival rate from 35 per cent to 55 per cent .

LINAC with patient in LabAid Specialised Hospital in Dhaka. Source: Dhaka Medical College and Hospital

Annex B: Radiotherapy treatment under RCA in Indonesia – case example

Background

In Indonesia, the first radiotherapy treatment took place in 1927, using a ray therapy unit to treat superficial skin lesions. In the following two decades, additional superficial and deep X-ray therapy units were established in the central general hospital in Jakarta. The first Cobalt-60 teletherapy unit was installed in 1958. Some years later, in 1982, the country's first linear accelerators (LINAC) were installed. Between 1980 and 2000, additional radiotherapy centres were created in other parts of Indonesia, thus improving accessibility to radiotherapy treatment for cancer patients outside of the island of Java. The Indonesian Radiation Oncology Society (IROS) was established in 2000, bringing together a wide range of radiation oncology professionals advocating for improved quality of life for cancer patients.

For the first 70 years of existence in Indonesia, radiation oncology developed as part of the discipline of radiology, and was limited to treatment that mainly consisted of conventional 2-dimensional treatment planning and delivery (2-D radiotherapy). No formal guidelines for treatment were established at the national level.

In 2007, Indonesia officially joined the radiotherapy programme under the RCA. In that same year, the establishment of the Indonesian College of Radiation Oncology under the IROS was approved, and RO became an independent discipline.

Indonesia's participation in the radiotherapy programme of the RCA contributed to strengthening education and training in radiation oncology, as well as increasing the investment in radiotherapy technology. These advancements have helped the country transition from conventional 2-D radiotherapy to more advanced conformal technologies, improving the access to radiotherapy treatment for cancer patients as well as the standard of care.

Strengthening of radiotherapy workforce

Participation in the radiotherapy programme of the RCA has made a significant contribution to strengthening radiation oncology education and training in Indonesia. First, the education curriculum of the country's only RO residency programme follows the guidelines established by IAEA. Second, through its projects RAS6086 and RAS6096[14], the RCA has empowered regional collaboration and sharing of best practices among RO experts. The establishment of the Federation of Asian Organizations for radiation oncology (FARO) and the establishment of online clinical networks are examples of the results from this collaboration. Finally, a series of regional training courses on the topics of brachytherapy, Intensity Modulated Radiation Therapy, and Stereotactic Body Radiation Therapy were held.[15]

Virtual Tumour Board Meeting under project RAS6096. Source: Indonesian Radiation Oncology Society (IROS)

14 RAS6086 'Strengthening Cancer Management Programmes in RCA States Parties through Collaboration with National and Regional Radiation Oncology Societies' and RAS6096 'Empowering Regional Collaboration among Radiotherapy Professionals through Online Clinical Networks'.

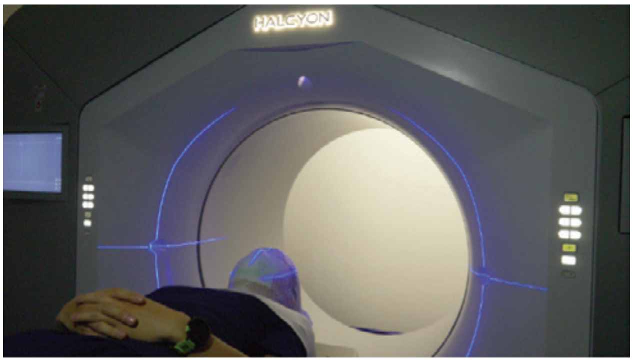
15 RAS6062 'Supporting 3D Image-Guided Brachytherapy Services', RAS 6072 'Strengthening Intensity Modulated Radiation Therapy capability in the RCA region', and RAS6085 'Enhancing Stereotactic Body Radiation Therapy for Frequent Cancers in the RCA region'.

3rd FARO Annual Meeting in Bali, Indonesia. Source: Indonesian Radiation Oncology Society (IROS)

As a result of these capacity-building activities, it is reported that between 2000 and 2020, the number of certified Radiation Oncologists, Medical Physicists, and Radiation Technology Therapists increased from 30 to 123, from 300 to 600, and from 126 to 367 respectively.

Adoption of radiotherapy technology

In 2000, there were only 20 radiotherapy treatment units in Indonesia, compared to the 200 needed to meet the needs of the Indonesian population at that time.[16] Today, this number has increased to 82 teletherapymachines and 22 brachytherapy units across 47 radiotherapy centres. This significant increase in the number of radiotherapy machines was triggered, to a great extent, by the strong advocation efforts made by the IROS regarding the need of investment in radiotherapy technology. These advocation efforts resulted in a series of public-private partnerships



The 'O' shaped Linear Accelerator (LINAC) with high precision radiation techniques, the first in Indonesia. Source: Indonesian Radiation Oncology Society (IROS)

which led to an increase in the number of available of equipment. The RCA has also contributed to the increase in the availability of radiotherapy technology by investing in the installation of Cobalt-60 teletherapy units in Banjarmasin and Borneo Island.

Furthermore, under project INS6015 'Improving Quality for Cancer Management through Improved Medical Physics Services', the

16 WHO's standards recommend one radiotherapy machine per million people

RCA supported the establishment of a tele-radiotherapy network. By providing the expertise to design the network and donating the necessary hardware, eight medical centres can now share diagnostic and radiotherapy treatment plan information with the main Dr. Cipto Mangunkusumo Hospital in Jakarta. This improves the quality of radiotherapy treatment in locations situated far from urban centres. This is an important development because providing equal access across the extensive Indonesian archipelago is challenging.

Social and economic effects

The training of radiotherapy specialists, the creation of regional expert networks and sharing of best practices, and the investment in radiotherapy technology has contributed to improvements in the accessibility and quality of radiotherapy treatment for cancer patients in Indonesia. The number of cancer patients treated with radiotherapy technology went from 10 000 in 2000 to 40 500 in 2020. Furthermore, the larger number of radiotherapy centres and machines has reduced the waiting time for radiotherapy treatment among cancer patients with the proportion of patients waiting for radiotherapy treatment for over 10 days more than halving between 2000 and 2020.

The number of cancer patients treated with radiotherapy technology went from 10 000 in 2000 to 40 500 in 2020.

With the advancement of radiotherapy technology, improvements in treatment quality and effectiveness are occurring. For example, larger doses of radiotherapy can now be better targeted, thus destroying cancer cells with less harm to healthy tissue and vital organs. Participation in the RCA has also encouraged the inclusion of radiotherapy as one of the essential treatments in the multidisciplinary approach to cancer treatment in Indonesia, giving cancer patients more comprehensive and higher quality care. It is estimated that the average 5-year control and survival rates have increased from 50 per cent to 70 per cent, and from 50 per cent to 60 per cent, respectively.

Training session by Dr. Erdenetuya under RAS6062 project in 2017. Source: National Cancer Center

Annex C: Radiotherapy treatment under RCA in Mongolia – case example

Background

In 1959, the first X-ray treatment cabinet[17] was established in the capital of Mongolia. Two years later, a specialized radiotherapy hospital (State Radiation Hospital) opened, and the first Cobalt-60 teletherapy machine was installed. The hospital continued expanding its radiotherapy services to cancer patients over the next twenty years and became the State Oncology Centre in 1982.[18] A new hospital building with additional radiotherapy equipment[19] was constructed at that time.

The radiotherapy department of the State Oncology Centre used telecobalt and brachytherapy devices manufactured in the Soviet Union until 1997. With the dissolution of the Soviet Union, critical interruptions in the maintenance of these devices were common. Furthermore, national radiotherapy department staff did not have sufficient knowledge and experience to work with the radiotherapy technology and equipment.

Subsequently, Mongolia joined the radiotherapy programme under the RCA in 1997. Participation in the RCA has led to the modernization of radiotherapy equipment in the country, and increased opportunities for training in radiotherapy technology developments for national radiotherapy specialists.

Strengthening of radiotherapy workforce

Under the radiotherapy programme of the RCA, national Radiation Oncologists, Medical Physicists, and Radiation Therapy Technicians have participated in a wide range of regional seminars, expert missions and knowledge sharing workshops. These training activities have strengthened the knowledge and capabilities of radiotherapy experts in the use of newer and more effective radiotherapy treatment modalities. For example, through participation in the RAS6062 and RAS6072 projects[20], national radiotherapy experts strengthened their capacity in implementing 3D Image-Guided Brachytherapy (3D-IGBT) and Intensity Modulated Radiotherapy (IMRT) techniques in a safe and effective manner. As a result, trained medical staff now develop radiotherapy treatment protocols in accordance with international clinical guidelines of quality control, leading to considerable improvements in the quality of the treatment received by patients.

Cooperation with the RCA has also contributed to increasing awareness among the medical community of the benefits of radiotherapy treatment for cancer patients. In 2014, this led to the creation of a six-month radiation oncology training programme at the National Cancer Centre (NCC). This training programme has the support of the Health Development Centre under the Ministry of Health, and six Radiation Oncologists have successfully graduated from it. Five of these specialists are currently working in the NCC.

17 Equipped with two ROUM-7 and ROUM-11 units.

18 In 2006 it was expanded again and renamed as National Cancer Centre (NCC).

19 New equipment included AGAT-C telecobalt and ROKUS-M high energy x-ray units and AGAT-B brachytherapy units.

20 RAS6062 'Supporting 3D Image-Guided Brachytherapy Services', and RAS 6072 'Strengthening Intensity Modulated Radiation Therapy capability in the RCA region'.

First patient treatment with LINAC in June 2019, with the collaboration of an Australian Radiation Technology Therapist, Toby Lowe. Source: National Cancer Center

Adoption of radiotherapy technology

In 1997, supported by the radiotherapy RCA project RAS6021, Mongolia first applied a conventional 2-dimensional treatment with Radiotherapy after Oesophageal Cancer Stenting (ROCS). Dosimetry systems were incorporated into radiotherapy treatments from 1998, making more accurate measurements of radiation doses possible, thus improving the safety and effectiveness of radiotherapy treatments.

Moreover, the RCA has supported the introduction of more advanced radiotherapy technologies in the country, expanding the scope, scale, and quality of the NCC's services. For example, in 2018[21], 3D-IGBT was officially introduced to provide more effective radiation treatment for cervical cancer, minimising the side effects for normal, healthy organs and tissue. In 2019, the first Linear Accelerators (LINAC) were installed in the country, and the first 3D conformal radiotherapy (3D-CRT) procedures were delivered. It is estimated that today, 98 per cent of all cancer patients can undergo and benefit from 3D-CRT.

In 2019, the first Linear Accelerators (LINAC) were installed in the country, and the first 3D conformal radiotherapy (3D-CRT) procedures were delivered.

Finally, an ongoing project[22] supported by the RCA is helping the country prepare for the introduction of other sophisticated, high-precision radiotherapy techniques such as Stereotactic Body Radiation Therapy and IMRT.

Social and economic effects

The accessibility to radiotherapy treatment for cancer patients has improved with the introduction of more advanced radiotherapy technology and strengthened technical competencies of radiotherapy medical staff. It is estimated that the number of cancer patients treated with radiotherapy technology has increased from 300 in 2000 to 812 in 2020.

Increased accessibility to cancer treatment in the country means fewer cancer patients having to travel to foreign countries for treatment, reducing the costs for patients and their families. Similarly, the hypo-fractionation[23] of modern radiotherapy treatment schemes has reduced the time patients have to spend having treatment, thus making shorter trips for treatment possible and further reducing the costs for families who live in rural areas or far from the capital.

Finally, Mongolia's collaboration under the RCA has increased awareness and knowledge in the general population of the benefits and importance of undergoing radiotherapy treatment for cancer. An increasing number of patients are now willing to seek radiotherapy treatment earlier instead of relying solely on traditional therapy or surgery methods.

21 MON6018 'To improve Brachytherapy Quality Assurance Through Introducing 3D Image-Guided Brachytherapy Service in Mongolia'

22 MON6021 'Improving the Quality of Radiotherapy Services for Common Cancers through the Implementation of Linear Accelerator Based Stereotactic Body Radiation Therapy'

23 The process of dividing a dose of radiation into multiple 'fractions', with the objective of maximizing the destruction of malignant cells while minimizing damage to healthy tissues.

Annex D: Radiotherapy treatment under RCA in Thailand – case example

Background

Radiotherapy treatment for cancer patients was first introduced in Thailand in the late 1930s when national radiation oncologists, trained in the United States and the United Kingdom, began making use of a deep X-ray 230KV machine and a Ra226 brachytherapy unit. Almost thirty years later, in 1958, the first Cobalt-60 teletherapy machine was established. Much later, in 1982, the first Linear Accelerator (LINAC) was introduced in the country.

For the first seventy years of development, access to cancer treatment with radiotherapy technology was mostly limited to the university hospital in Bangkok. Furthermore, the number of medical specialists trained and qualified in radiotherapy methods was minimal. It was not until the late 1990s that radiotherapy for cancer treatment slowly became more accessible in other regions of the country, including in private hospitals, although the major developments in radiation oncology have taken place over the past 20 years.

In 2005, Thailand joined the radiotherapy programme under the RCA. Participation in the RCA has contributed to strengthening the radiation oncology workforce and accelerated the successful and safe implementation of sophisticated radiotherapy services in the country.

Strengthening of radiotherapy workforce

Since the early stages of collaboration with the RCA, the main focus for Thailand has been capacity building through the provision of short-term training courses, scientific visits, and regional expert missions and workshops. These capacity building activities have contributed to enhance the capacity of national experts in applying effective radiotherapy treatment modalities such as Intensity Modulated Radiation Therapy (IMRT)[24] or 3D Image-Guided Brachytherapy, as well as to expand the awareness raising and knowledge sharing role of the Thai Society of Therapeutic Radiology and Oncology (THASTRO)[25].

The radiotherapy programme of the RCA has also contributed to the development of some specialised short-term courses, such as those focused on radiotherapy quality assurance. These are delivered as part of the training curriculum of the national residency programme in radiation oncology.

These training activities have improved the knowledge and skills of a national cohort of medical experts in radiotherapy treatment for cancer patients. Indeed, between 2000 and 2020, the number of certified Radiation Oncologists, Medical Physicists, Radiation Technology Therapists,

National 3D Image-Guided Brachytherapy workshop on gynecologic malignancy at Siriraj hospital in October, 2019. Source: Faculty of Medicine, Chiang Mai University

24 RAS6072 ‘Strengthening Intensity Modulated Radiation Therapy (IMRT) Capability in the Region’

25 RAS6086 ‘Strengthening Cancer Management Programmes in RCA States Parties through Collaboration with National and Regional Radiation Oncology Societies’

and Radiation Oncology Nurses more than doubled across all categories of staff.[26]

Adoption of radiotherapy technology

Participation in the RCA also encouraged the interest of national radiation oncology teams in more advanced radiotherapy technologies, which led to the introduction of new radiotherapy technology in a larger number of cancer treatment centres. For example, in 2005, IMRT was officially introduced in the country, followed by 3D Image-Guided Brachytherapy in 2011. These new technologies have improved quality and access to radiotherapy treatment across the country.

148 operational radiotherapy machines in Thailand

119 teletherapy

29 brachytherapy machines distributed across

43 radiotherapy centres within the public and private sectors.

This is a major advance since 2000, when the country only had 50 radiotherapy machines. Over the past 20 years, Thailand has succeeded in reaching WHO's recommended target of one radiotherapy machine per million people, although some additional improvements are still needed in terms of regional availability of these services.

Social and economic effects

Thailand's participation in the radiotherapy programme of the RCA has contributed to the introduction of highly advanced radiotherapy

Patient setup and position verification for radiation therapy
Source: Faculty of Medicine, Chiang Mai University

technologies and strengthened the technical skills and competencies of its national radiotherapy specialists in these technologies. Consequently, access to radiotherapy treatment for cancer patients has improved. It is estimated that the number of cancer patients treated with radiotherapy technology increased from 20 000 in 2000, to 50 000 in 2020.

The adoption of improved radiotherapy technology has also improved the quality of treatment for cancer patients. With the introduction of novel treatment modalities, cancer patients can now be treated more effectively with less (or even absence of) related morphological damage. This has contributed to an approximate increase from 40 per cent to 60 per cent in the average 5-year control rate in the past two decades, and an increase from 45 per cent to 65 per cent in the average 5-year survival rate.

Finally, Thailand's participation in the radiotherapy programme of the RCA has led to the recent creation of its own national team for the quality assurance of radiotherapy treatment[27]. This is a highly significant development in improving the quality of care received by cancer patients in the country.

26 Radiation Oncologists increased from 70 to 179; Medical Physicists increased from 50 to 154; Radiation Technology Therapists increased from 150 to 340; and Radiation Oncology Nurses increased from 25 to 50.

27 The first 'Quality Assurance Team for Radiation Oncology (QUATRO)' training was delivered in Thailand 2018. This was the seed for establishing a Thai-QUATRO (T-QUATRO) team, an idea which was further supported by other technical cooperation projects in 2019.

Annex E: Survey Analysis

Introduction

This Annex presents the findings of the Social and Economic Impact Assessment of the RCA's contribution to Radiotherapy in the Asia and Pacific region. The data that informs the analysis was collected through an online survey that was designed and piloted in May 2021 and deployed between June and August 2021. The respondents to the survey were national experts in the field of radiotherapy. They provided relevant information about the educational programmes on radiotherapy available, radiation oncology departments, radiation oncology societies, radiotherapy specialists, and the life span and quality of life of patients that the RCA has contributed to achieve in their countries.

Out of the 22 countries that are part of RCA, 21 participated in the IAEA's radiotherapy online survey: Australia, Bangladesh, Cambodia, China, India, Indonesia, Japan, Laos, Malaysia, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, Palau, Philippines, Singapore, South Korea, Sri Lanka, Thailand, and Vietnam. Figure 3 below shows the countries that participated in this study.

Figure 3: Map of the 20 countries that participated in the online survey

To understand the contribution of the RCA on social and economic indicators related to radiotherapy, the study analysed the extent to which being part of the programme has enabled the State Parties to:

Strengthen radiotherapy workforce

- Offer educational training programmes, and establish radiation oncology departments and societies.
- Develop specialists in the area of radiation oncology, such as Radiation Oncologists, Medical Physicists, Radiation Technology Therapists, and Radiation Oncology Nurses.

Increase access to quality radiotherapy

- Increase the availability of operational radiotherapy equipment and technology.
- Increase the number and quality of treatment of cancer patients using domestic radiotherapy facilities.

Increase life span and quality of life

- Increase in local control rates.
- Increase in survival rates.

The IAEA Technical Cooperation Programme (TCP) supports RCA State Parties (especially developing countries) to accelerate and enlarge the application of nuclear technologies in a safe, secure, effective, and efficient manner. In principle, every IAEA Member State can receive and enjoy the benefit of the IAEA TCP. However, some State Parties (especially developed/advanced countries) volunteer not to receive support from the IAEA TCP, but they work as resource countries to provide support for the IAEA TCP. Under the RCA, there are 22 countries, of which 18 countries are TC recipients and 4 are TC non-recipients (Australia, Japan, New Zealand and since 2010 South Korea). Based on this definition, the three countries that have historically acted as non-recipients (Australia, Japan and New Zealand) are excluded from the assessment of the criteria and level of performance conducted in this analysis. Given their historically non-recipient character, any assessment of the performance of RCA to accelerate and enlarge the application of radiotherapy technologies in those countries would result in a misinterpretation of the results.

Pre-defined criteria were agreed with IAEA and State Party experts to provide an evaluative framework for the impact assessment (Tables 12–14, Annex G). Figure 4 summarises the performance of the RCA for each State Party against the defined criteria (aspects of performance) and standards (levels of performance). Note that these ratings apply to the contribution of the RCA to social impacts in each country – they do not represent the performance of the individual countries. Note that Palau only joined the radiotherapy RCA recently, in 2019.

The complete analysis for all the aspects of performance is presented in the next sections.

	Vietnam	Philippines	China	Mongolia	Sri Lanka	Malaysia	Indonesia	South Korea	Thailand	Nepal	Myanmar	India	Cambodia	Bangladesh	Pakistan	Singapore	Laos	Palau	OVERALL
Criterion 1: Strengthened radiotherapy workforce	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0	1.0	1.0	1.0	0.0	1.9
Criterion 2: Increased access to quality radiotherapy	2.8	3.0	2.8	1.3	1.5	2.5	2.8	2.3	2.5	1.8	2.0	1.0	2.0	1.8	1.5	1.0	0.7	0.0	1.8
Criterion 3: Increased life span and quality of life	2.5	3.0	3.0		3.0	3.0	2.5	2.5	2.5	2.0	2.0	1.5	2.5	2.0	2.0	2.5			2.4

Figure 4: Rating of RCA contribution to social impacts by criteria and State Party

Criterion 1: Strengthened radiotherapy workforce

To understand the contribution of the radiotherapy RCA to developing the capacity and capability of the State Parties to strengthen their radiotherapy workforce, this section presents survey results indicating the extent to which the support of the radiotherapy RCA has enabled State Parties to:

- Offer educational training programmes, and establish radiation oncology departments and societies
- Produce specialists in the area of Radiation Oncology, such as Radiation Oncologists, Medical Physicists, Radiation Technology Therapists, and Radiation Oncology Nurses.

Key indicators and results of this assessment are summarised in the below table.

Sub-criterion	Evidence	Finding
Offer educational training programmes, and radiation oncology departments and societies	Total number of educational/ training programmes on radiotherapy available in 2020	116
Offer educational training programmes, and radiation oncology departments and societies	Total number of radiation oncology departments in 2020	3 215
Offer educational training programmes, and radiation oncology departments and societies	Total number of radiation oncology societies in 2020	94
Produce radiotherapy specialists	Approximate number of radiotherapy specialists in 2020	67 068
Produce radiotherapy specialists	Increase in number of radiotherapy specialists between 2000 and 2020	231.9%

Table 1: Key evidence for criterion 1: Strengthened radiotherapy workforce

Criterion 1.1 Offer educational training programmes, and establish radiation oncology departments and societies

To have an approximation of the capacity of each State Party to strengthen its radiotherapy workforce, survey respondents estimated the number of educational/training programmes on radiotherapy, radiation oncology departments and radiation oncology societies available in each country.

Educational training programmes

As can be seen in Figure 5, there are a total of 116 educational/training programmes (ET) on radiotherapy available across all the State Parties of the RCA. Vietnam and China are the countries where more training programmes on radiotherapy are available

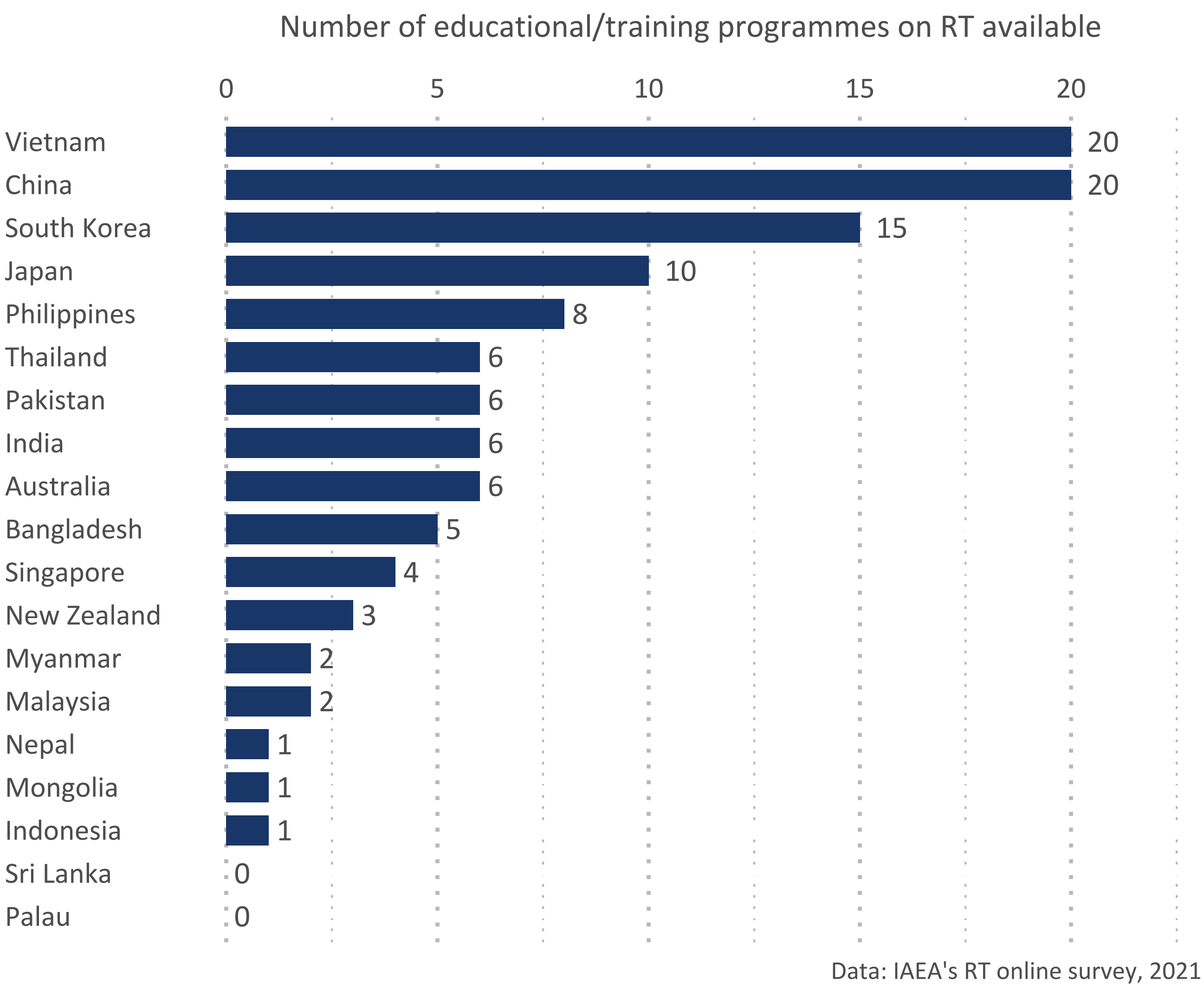


Figure 5: Number of educational or training programmes on radiotherapy available by State Party

(20 each), followed by South Korea and Japan where 15 and 10 ETs are available.

According to the responses of the State Parties, there are no training programmes on radiotherapy available in Palau, and Sri Lanka. Cambodia and Laos did not reported this information in the online survey.

Radiation Oncology Departments

There is a total of 3 215 radiation oncology departments across all the State Parties, with the majority of these located in China, Japan, and India. Figure 6 shows the number of radiation oncology departments available in each State Party.

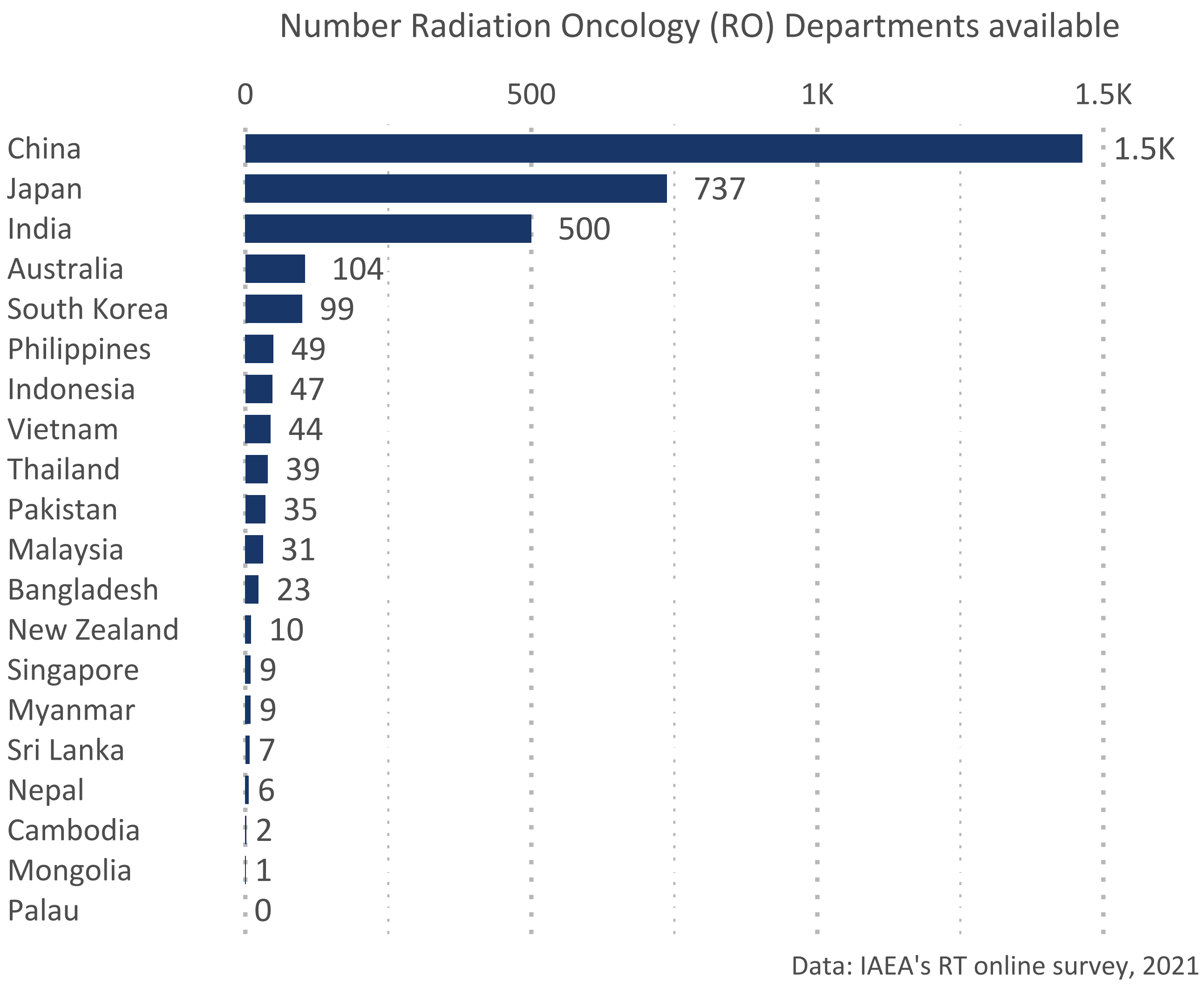


Figure 6: Number of radiation oncology departments by State Party

Radiation Oncology Societies

Across all the State Parties there are a total of 94 Societies, of which 61 are regional (subnational) and 33 are national societies. The countries with the largest number of societies are China (39), India (14) and Japan (5). Australia, Mongolia, Myanmar, Nepal, New Zealand, Sri Lanka, Thailand, and Vietnam have societies at the national level but not at the regional level. Figure 7 shows the number of national and regional radiation oncology societies established across the State Parties.

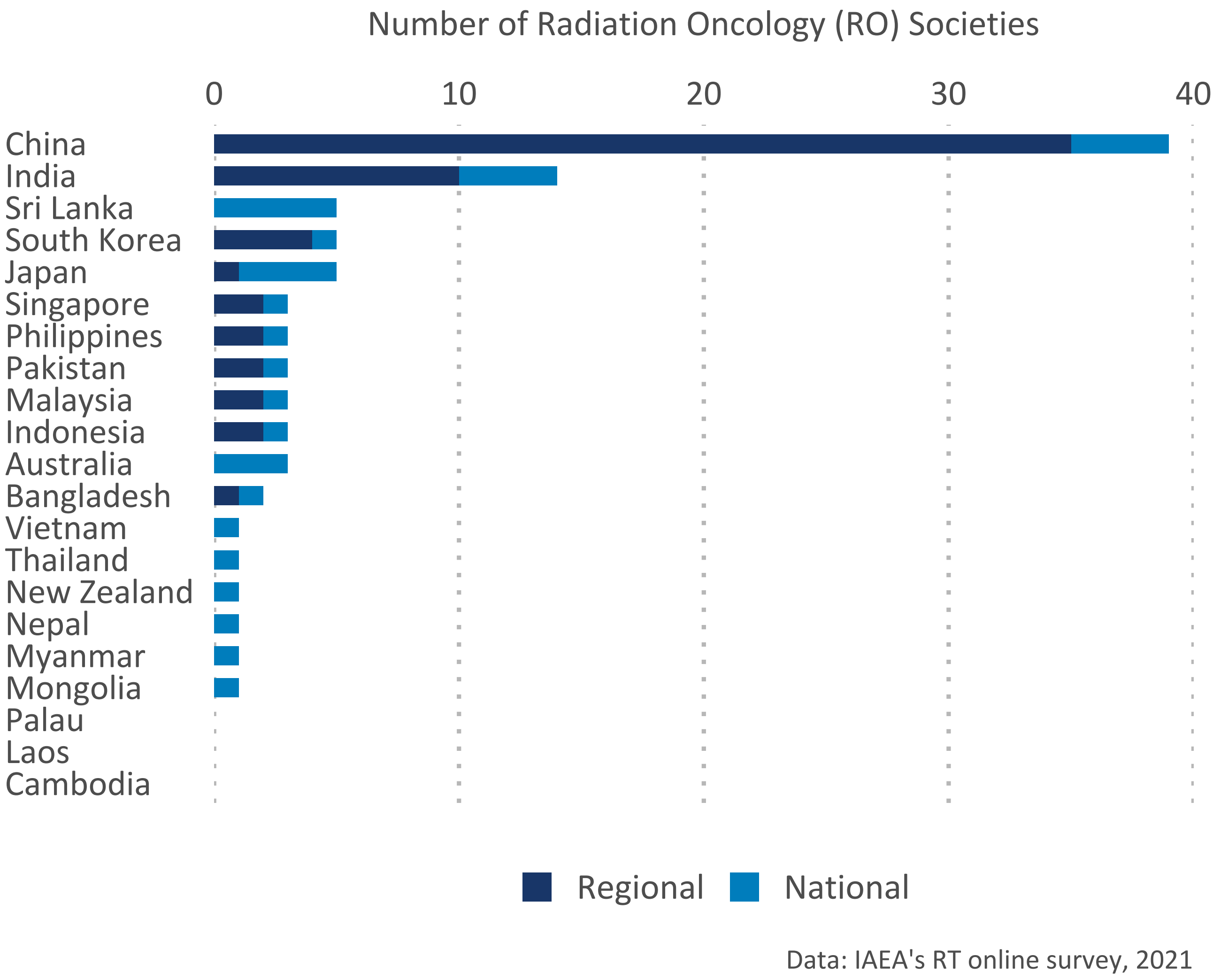


Figure 7: Number of radiation oncology societies available by type and State Party

Criterion 1.2 Produce radiotherapy specialists

67 068

radiotherapy specialists estimated in 2020 across all the State Parties

The country with the most radiotherapy specialists is China with 44 721 specialists, followed by India and Japan that have produced 7 003 and 6 656 specialists respectively. Most specialists (30 088) have been trained in the area of radiation oncology.

Figure 8 shows the total number of radiotherapy specialists that were certified in 2020 by radiotheraphy method in each State Party.

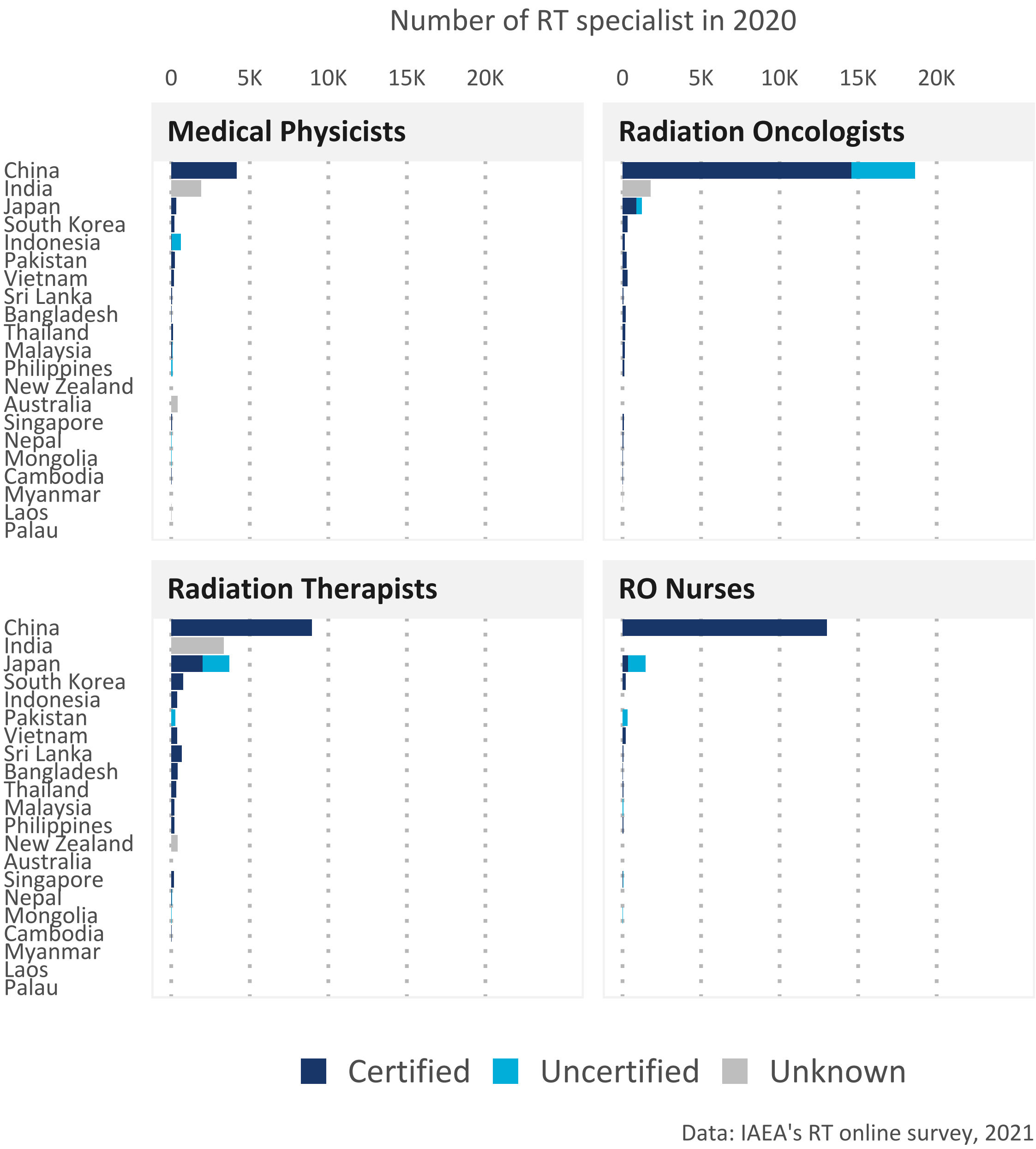


Figure 8: Number of radiotherapy specialists by State Party and type 2020

Australia, India, Laos, Myanmar, and New Zealand did not report, during the online survey, whether their radiotherapy specialist are certified or not. Thus, their bars are coded as 'Unknown' in the figure.

Radiotherapy specialists in 2000 and 2020

Figure 9 shows the distribution of radiotherapy specialists by country, across all the State Parties. There are 46 862 more radiotherapy specialists in 2020 than in 2000, with most of this growth occurring in China.

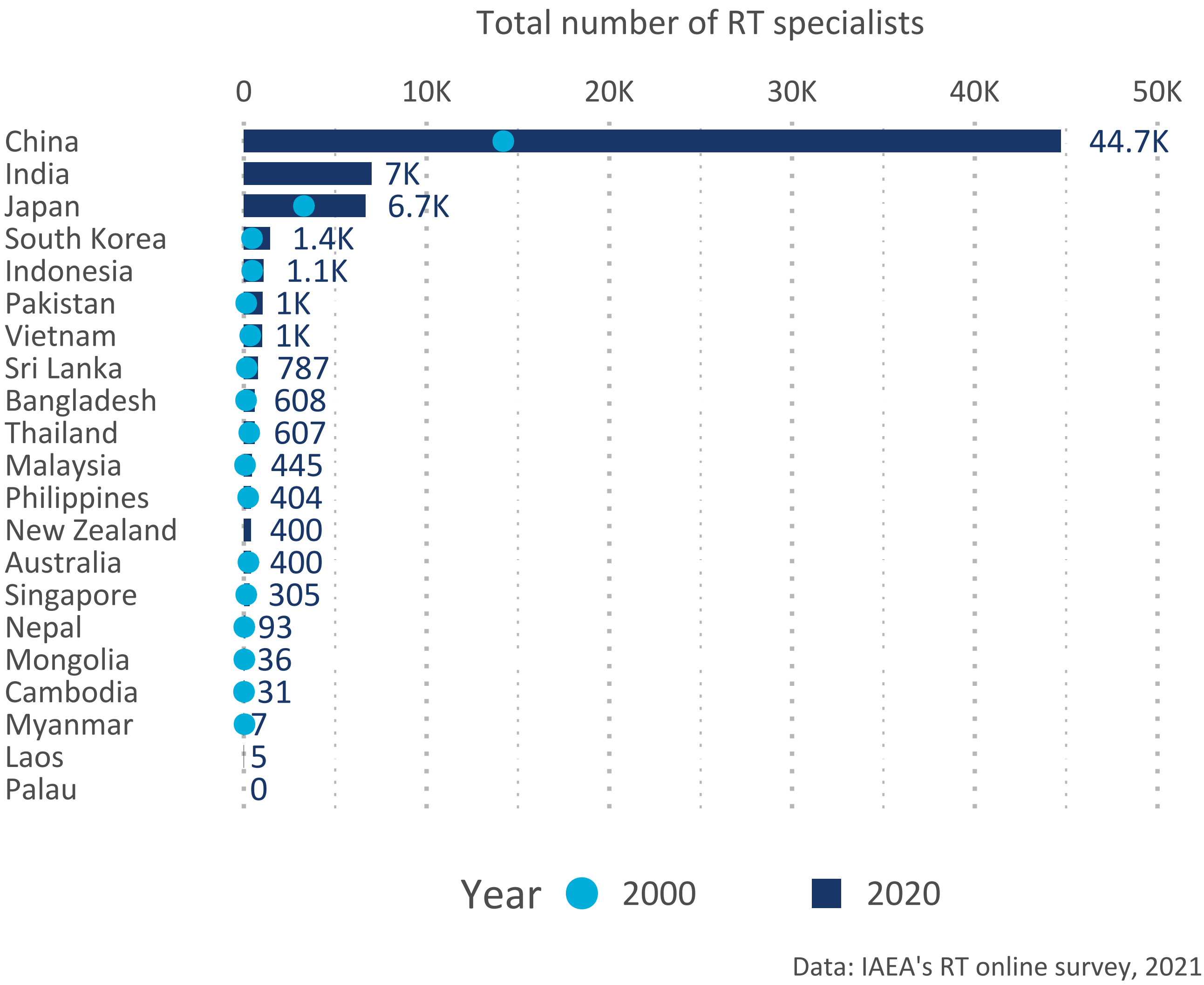


Figure 9: Number of radiotherapy specialists by State Party in 2000 and 2020

Figure 10 shows the percentage change in radiotherapy specialists between 2000 and 2020. In proportional terms, the greatest growth has occurred in Pakistan, followed by Malaysia, Bangladesh, and Sri Lanka.

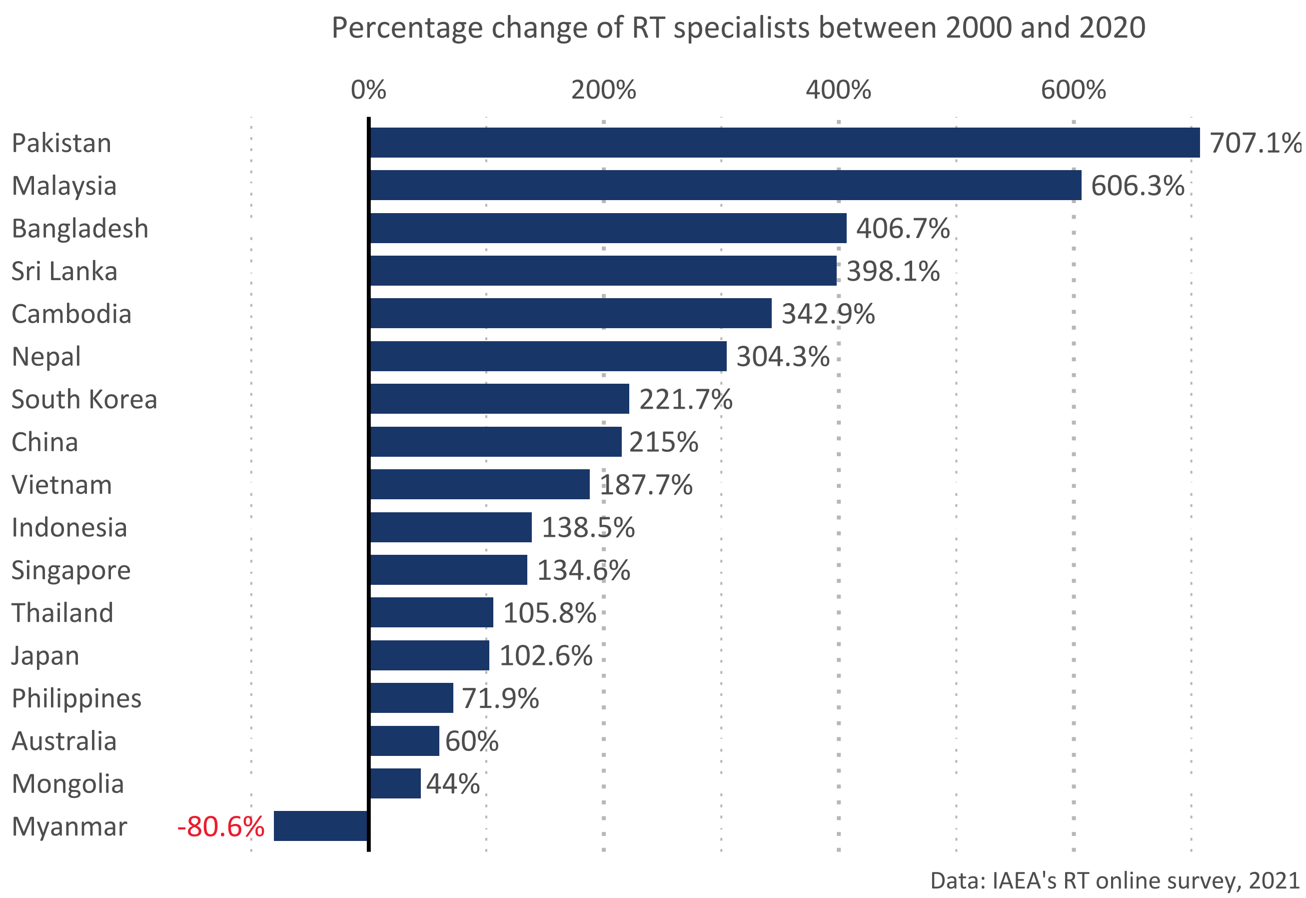


Figure 10: Percentage change in radiotherapy specialists between 2000 and 2020 by State Party

India, Laos, and New Zealand only reported the number of specialists in 2020, so percentage change could not be calculated. Myanmar was the only State Party to report a reduction in radiotherapy specialists. Although Myanmar reported to have Medical Physicists, Radiation Oncologists, Radiation Therapists, and RO Nurses in 2000, they did not report the number of Medical Physicists, Radiation Therapists, and RO Nurses.

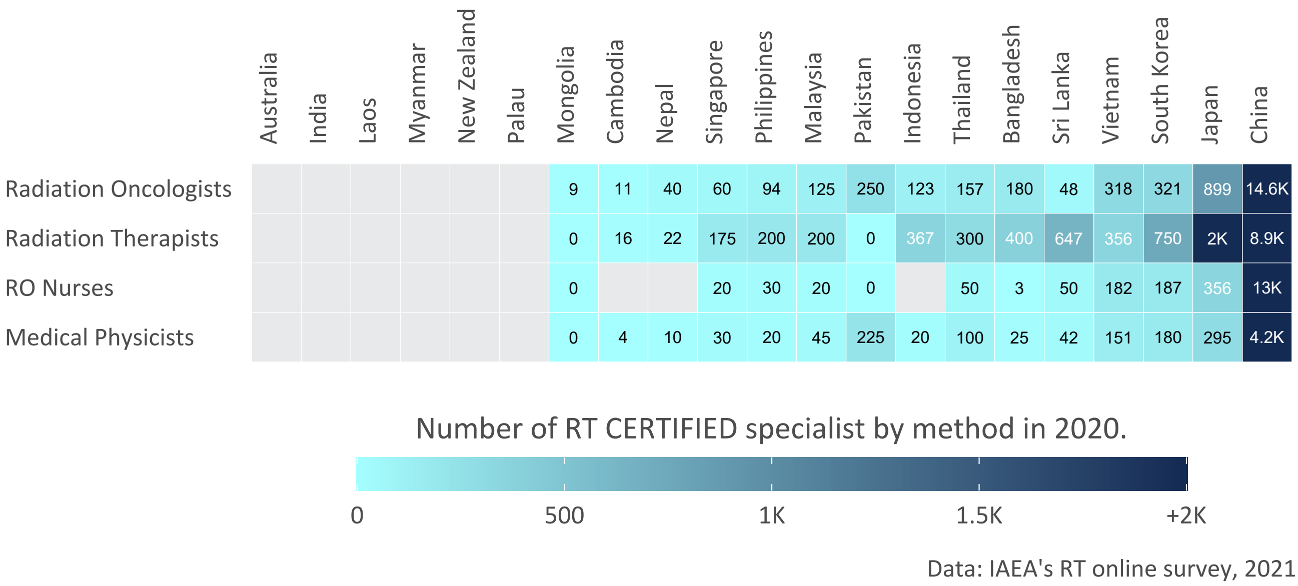


Figure 11: Number of certified radiotherapy specialists by State Party

Radiotherapy specialists by method

Figure 11 shows the distribution of certified specialists by method and by State Party in 2020 (grey shading indicates countries that did not report whether their specialists are certified). The country with the greatest numbers certified specialists is China, followed by Japan and South Korea.

Contribution of RCA in strengthening radiotherapy workforce

This section discusses the extent to which the State Parties perceived that the RCA contributed to the establishment of training programmes, radiation oncology departments, radiation oncology societies, and the production of radiotherapy specialists in their countries. Figure 12 shows that:

- Of the 17 State Parties with a training programme available domestically, 14 reported that RCA contributed to some extent in their establishment.
- Of the 19 State Parties where a radiation oncology department has been established, 14 reported that the RCA contributed to its establishment.
- Of the 18 State Parties where a radiation oncology society has been established, 13 reported that the RCA contributed to its establishment.
- Of the 19 historically recipient countries, 17 reported that RCA contributed to increasing numbers of radiotherapy specialists between 2000 and 2020.

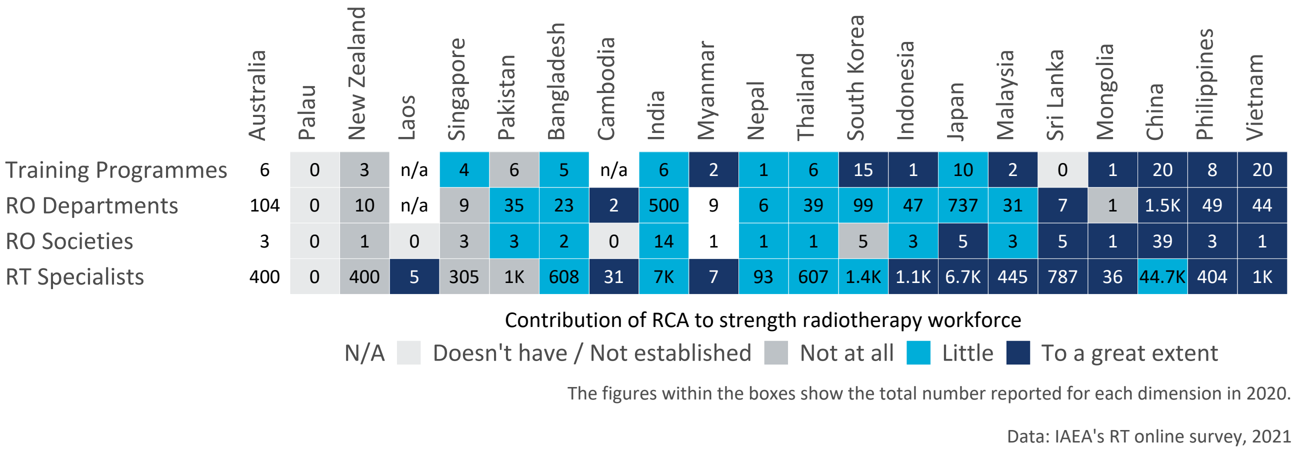


Figure 12: RCA contribution to strengthening radiotherapy workforce

The numbers within the boxes represent the total number of training programmes, radiation oncology departments, radiation oncology societies, and radiotherapy specialists that each State Party reported for the 2020 period. The white boxes indicate that those State Parties did not provide information about their perception of RCA's contribution in that dimension.

Criterion 2: Increased access to quality radiotherapy

This section summarises survey responses on the contribution of the radiotherapy RCA to increased access to quality radiotherapy in the State Parties. In particular, the objective of the analysis is to understand the extent to which the support of the radiotherapy programme has contributed to:

- Increasing operational radiotherapy equipment and technology.
- Increasing the number of cancer patients using domestic radiotherapy facilities.

Sub-criterion	Evidence	Finding
Increase operational radiotherapy equipment and technology	Total number of operational radiotherapy equipment (linear accelerators and Cobalt 60 machines) in 2020	4 599
Increase operational radiotherapy equipment and technology	% increase in the number of operational radiotherapy equipment (linear accelerators and Cobalt 60 machines) between 2000 and 2020	128.9%
Increase the number and quality of treatment of cancer patients using domestic radiotherapy facilities	Total number of cancer patients treated using domestic RT facilities in 2020	1 378 930
Increase the number and quality of treatment of cancer patients using domestic radiotherapy facilities	% increase in the number of cancer patients treated using domestic radiotherapy facilities between 2000 and 2020	120.5%
Increase the timeliness of treatment of cancer patients using domestic radiotherapy facilities	Proporton of patients that experienced less than 10 days of waiting time in 2020	60.8 %

Table 2: Key evidence for criterion 2: Increased access to quality radiotherapy

Criterion 2.1 Increase the availability of operational radiotherapy equipment and technology

Figure 13 shows the total number of operational radiotherapy equipment (linear accelerators and Cobalt 60 machines) available by State Party in 2000, 2010 and 2020.

Overall, in 2000, there were approximately 2 009 operational radiotherapy machines (linear accelerators and Cobalt 60 machines) across all the State Parties of the RCA. By 2020, this figure had increased to 4 599 which represents a percentage growth of 129 per cent over the 20 years.

China was the country with the greatest number of operational radiotherapy equipment available (2 087 machines) in 2020, as well as the greatest increase (1 091).

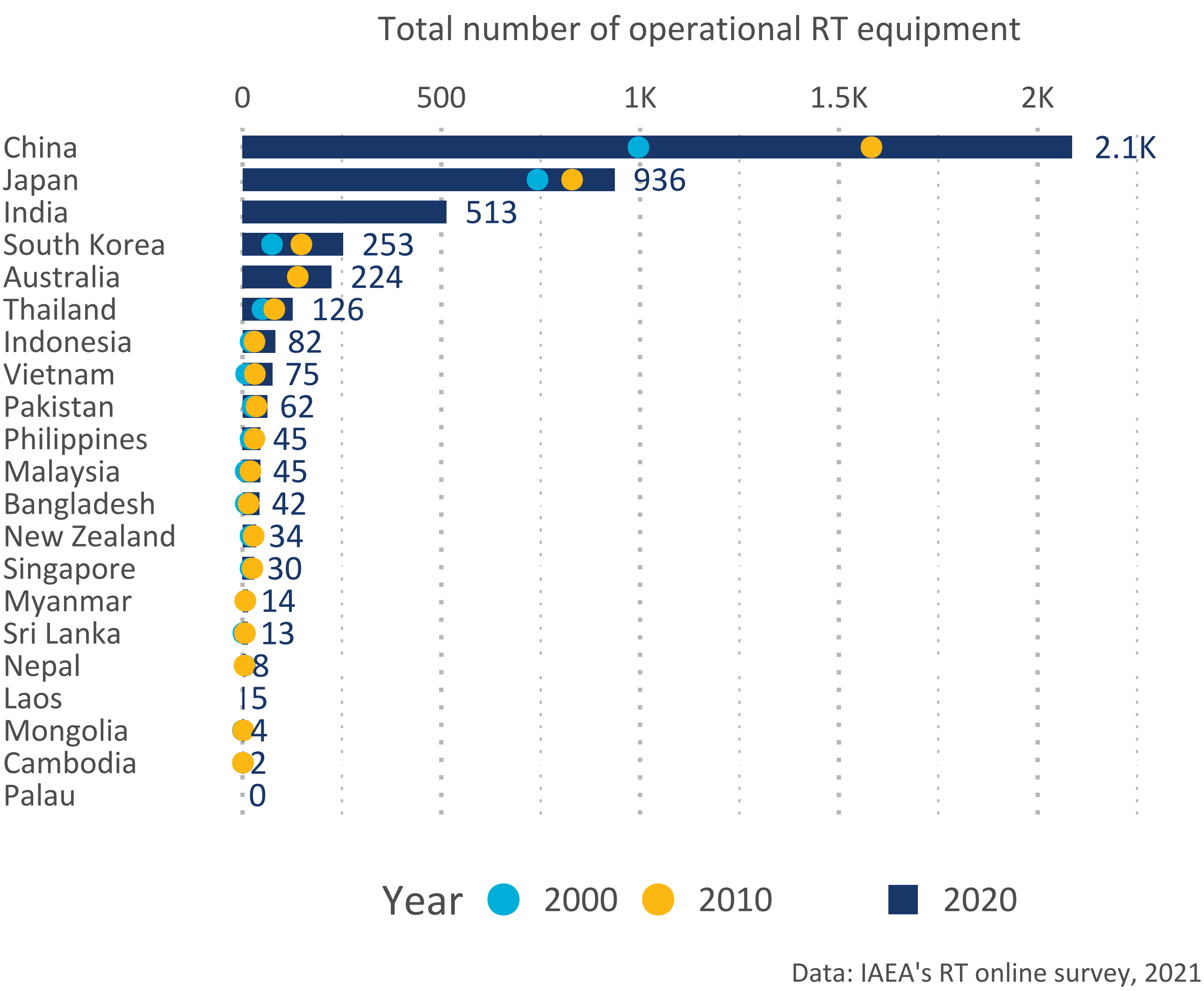


Figure 13: Total number of operational radiotherapy equipment (linear accelerators and Cobalt 60 machines) by State Party 2000, 2010, 2020

Figure 14 shows the percentage change in operational radiotherapy equipment between 2010 and 2020 by State Party.

By 2020, this figure had increased to 4 599 which represents a percentage growth of 129 per cent over the 20 years.

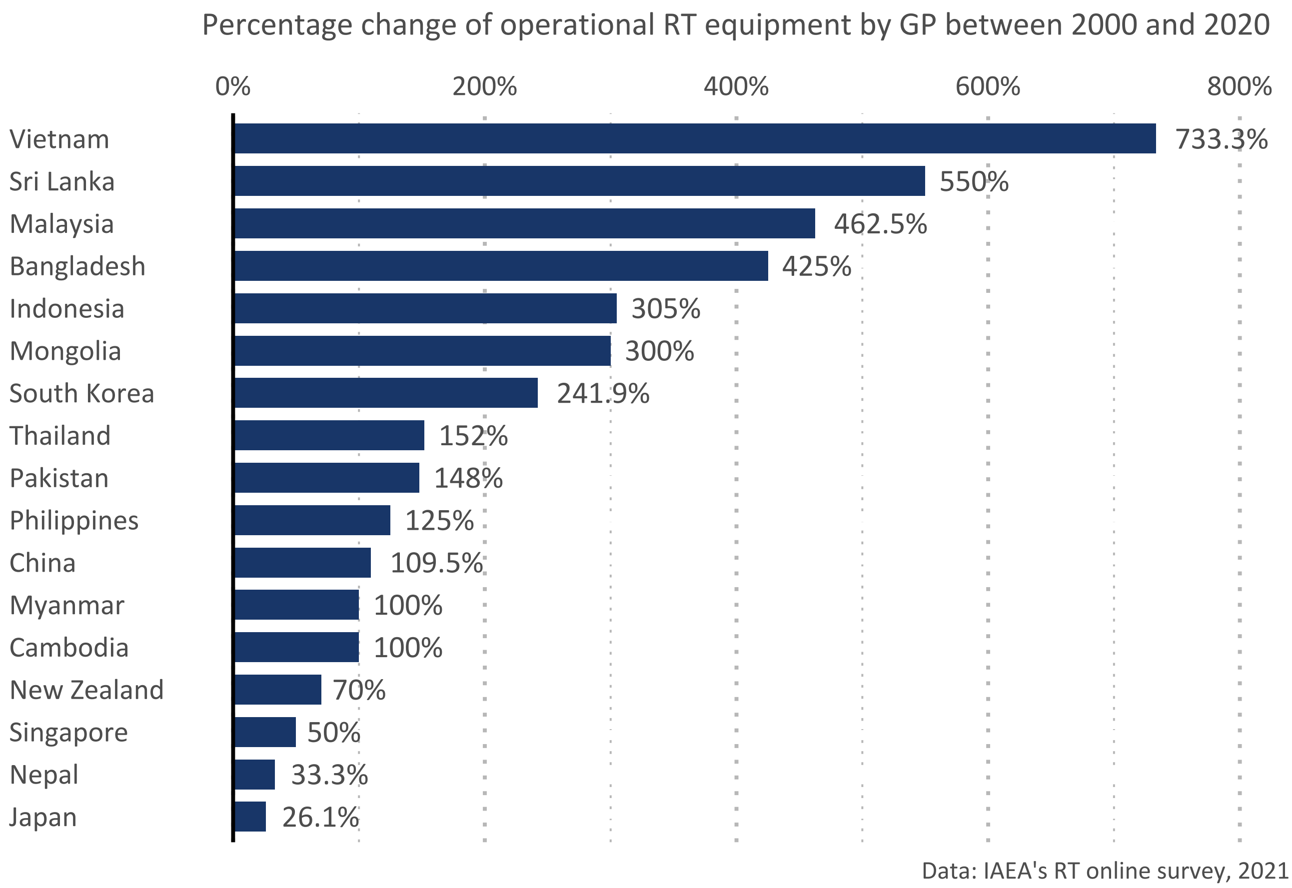


Figure 14: Percentage change of operational radiotherapy equipment (linear accelerators and Cobalt 60 machines) between 2000 and 2020 by State Party

Criterion 2.2 Increase the number and quality of treatment of cancer patients using domestic radiotherapy facilities

This section presents analysis of growth in total number of cancer patients treated and improvements in waiting times for the patients to be treated between 2000 and 2020.

Cancer patients treated using domestic radiotherapy

Overall, the number of cancer patients in RCA State Parties is reported to have more than doubled between 2000 and 2020 (Figure 15).

Figure 16 shows the percentage change in numbers of cancer patients treated using domestic radiotherapy facilities by State Parties between 2000 and 2020, with the greatest rates of growth seen in Bangladesh, Malaysia, and Indonesia.

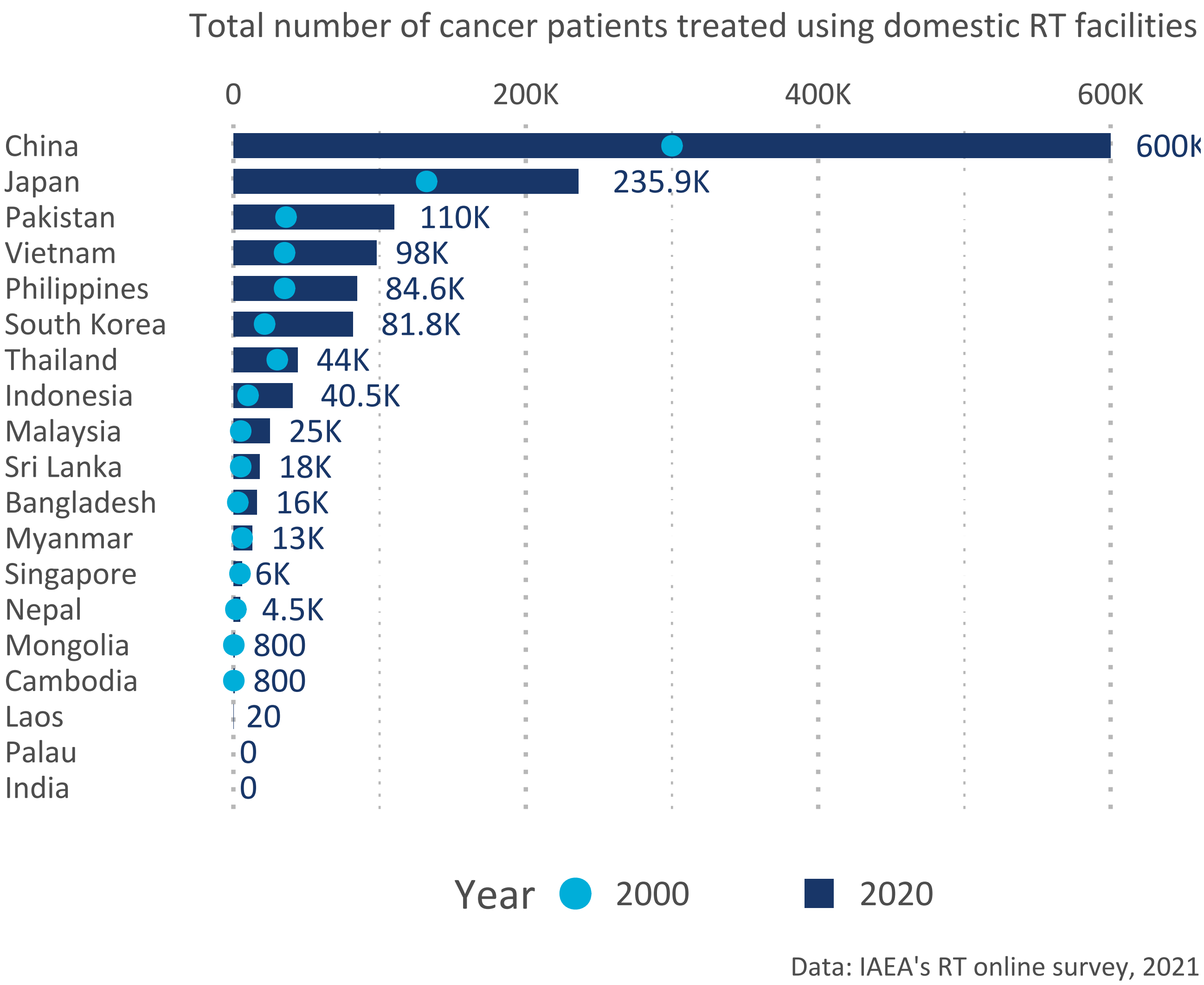


Figure 15: Total number of cancer patients treated using domestic radiotherapy facilities by State Party 2000 and 2020

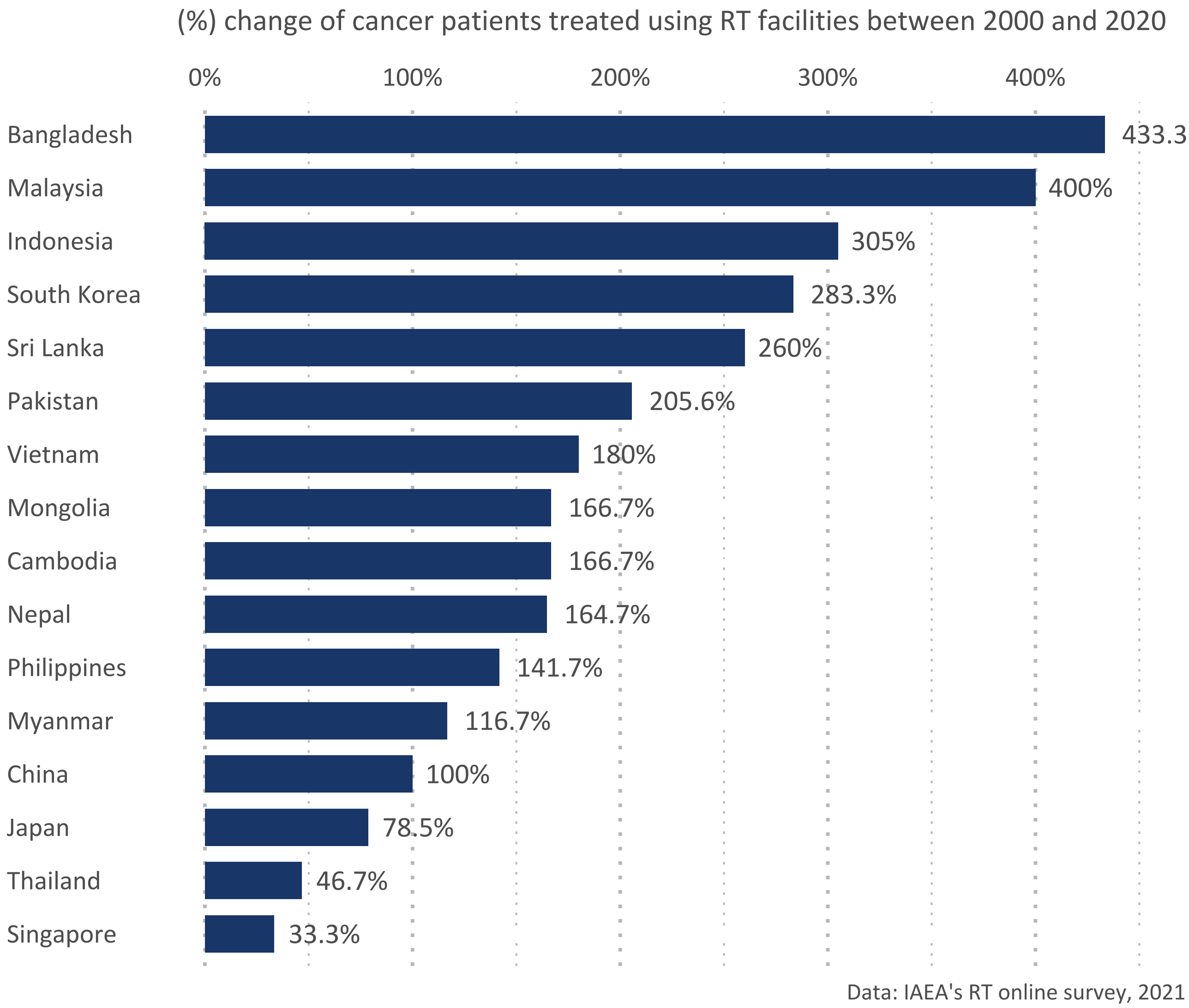


Figure 16: Percentage change in cancer patients treated using domestic radiotherapy facilities by State Party 2000 to 2020

Waiting times

Overall, the proportion of patients that experienced less than 10 days of waiting time has been fairly static between 2000 and 2020 (58.6 per cent versus 60.8 per cent). However, as can be seen in Figure 17, significant reductions of waiting times have been achieved in some individual RCA State Parties, while waiting times have also increased for a small number of other RCA State Parties.[28]

According to information provided by experts in Mongolia, the waiting times have increased because Mongolia made a transition from 2D to 3D technique in Radiation therapy planning in 2011 which is more time consuming than the 2D planning. Radiation oncologists needed to gain more experience in contouring target volumes and OAR. Experience of ROs and MPs is gradually increasing over time.

28 Waiting times can vary depending on the nature and urgency of treatment. However, in this survey, respondents were asked for the overall changes in waiting times, without disaggregation by treatment type or urgency.

Moreover, Pakistan reported that the waiting time for the start of radiotherapy has increased because the number of patients has increased manifold, but the number of equipment and qualified medical physicists, ROs and RTTs has not increased proportionately. Moreover, Palliative RT has started for most of the patients, but meticulous planning takes longer for curative RT. Also, there is a lot of patient load on RT machines. Contouring is done by postgraduate trainees and junior oncologists. Pakistan is in the process of hiring more MPs and RTTs and installation of more equipment. This will automatically reduce waiting time.

In Bangladesh, according to information provided by experts, the reason for an increase in waiting times is that the number of cancer patients is increasing but the number of cancer centres and machines are not increasing to meet the demand.

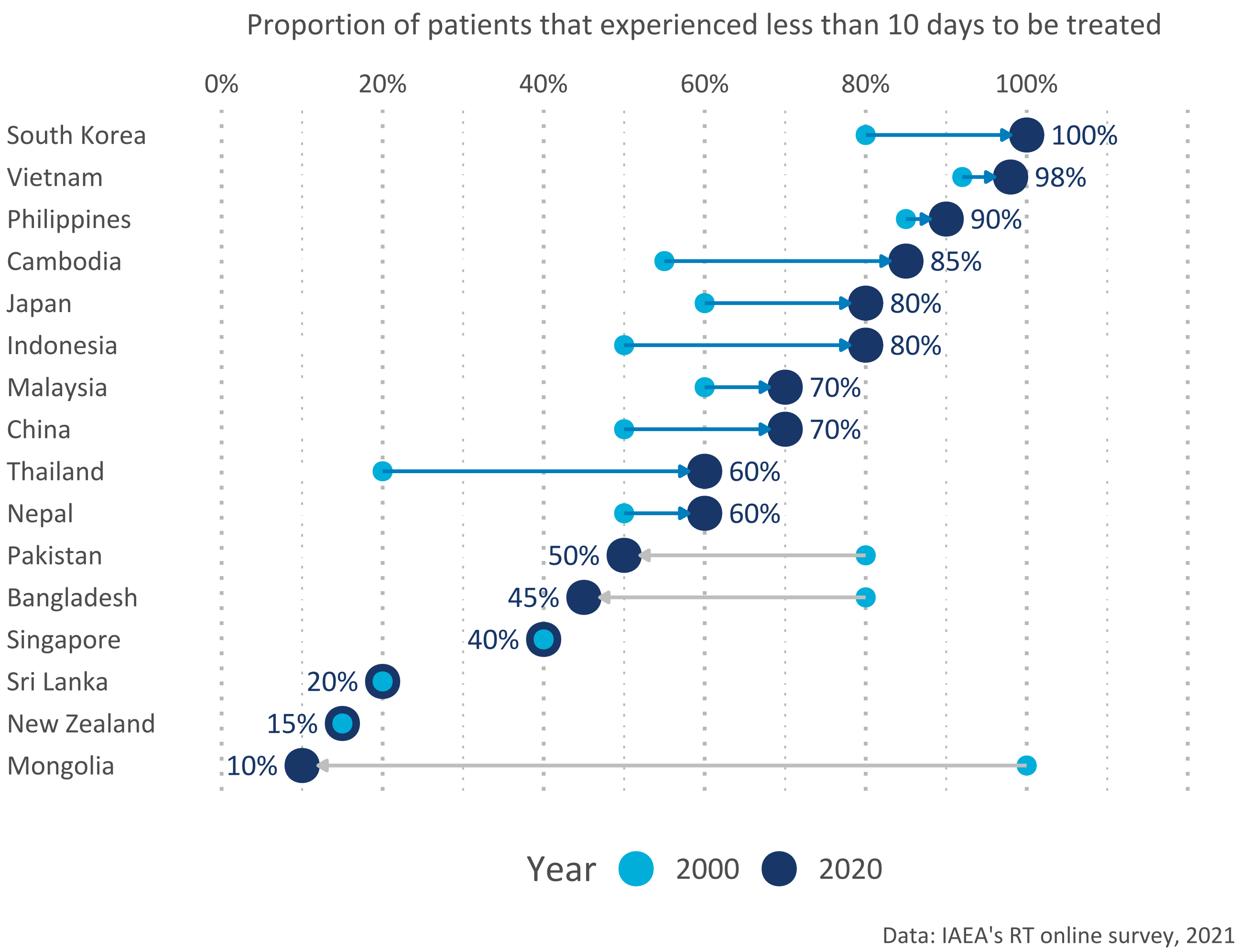


Figure 17: Proportion of patients that experienced less than 10 days waiting time by State Party and year

Figure 18 shows the proportion of patients treated by waiting time in 2020. The two highest performing State Parties by this measure were South Korea, where 100 per cent of the patients experienced less than 5 days of waiting times, and Vietnam, where 60 per cent of patients were treated in less than 5 days.

Australia, India, Laos, Myanmar, and Palau are not shown in the Figures because information about waiting times was not provided by these countries during the online survey.

The complete distribution of waiting times in the period 2000 to 2020 is presented in a supplementary table at the end of this Annex.

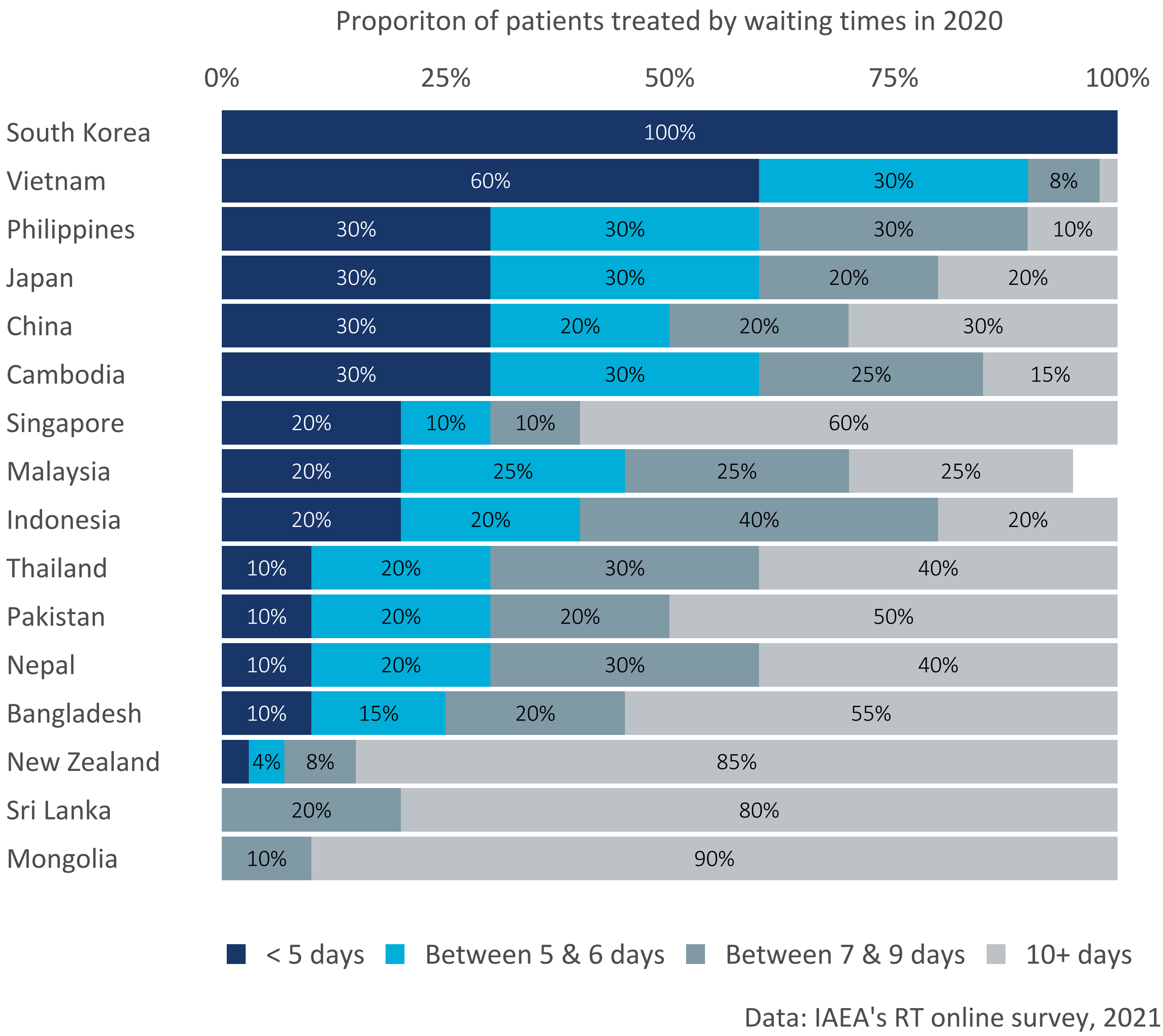


Figure 18: Proportion of patients treated by waiting time and State Party 2020

Population coverage

Figure 19 shows the approximate proportion (%) of the population in each country that lives within a radius of 100km from radiotherapy equipment (linear accelerators and Cobalt 60 machines). Singapore and South Korea reported that 100 per cent of their population live within a radius of 100km from radiotherapy equipment.

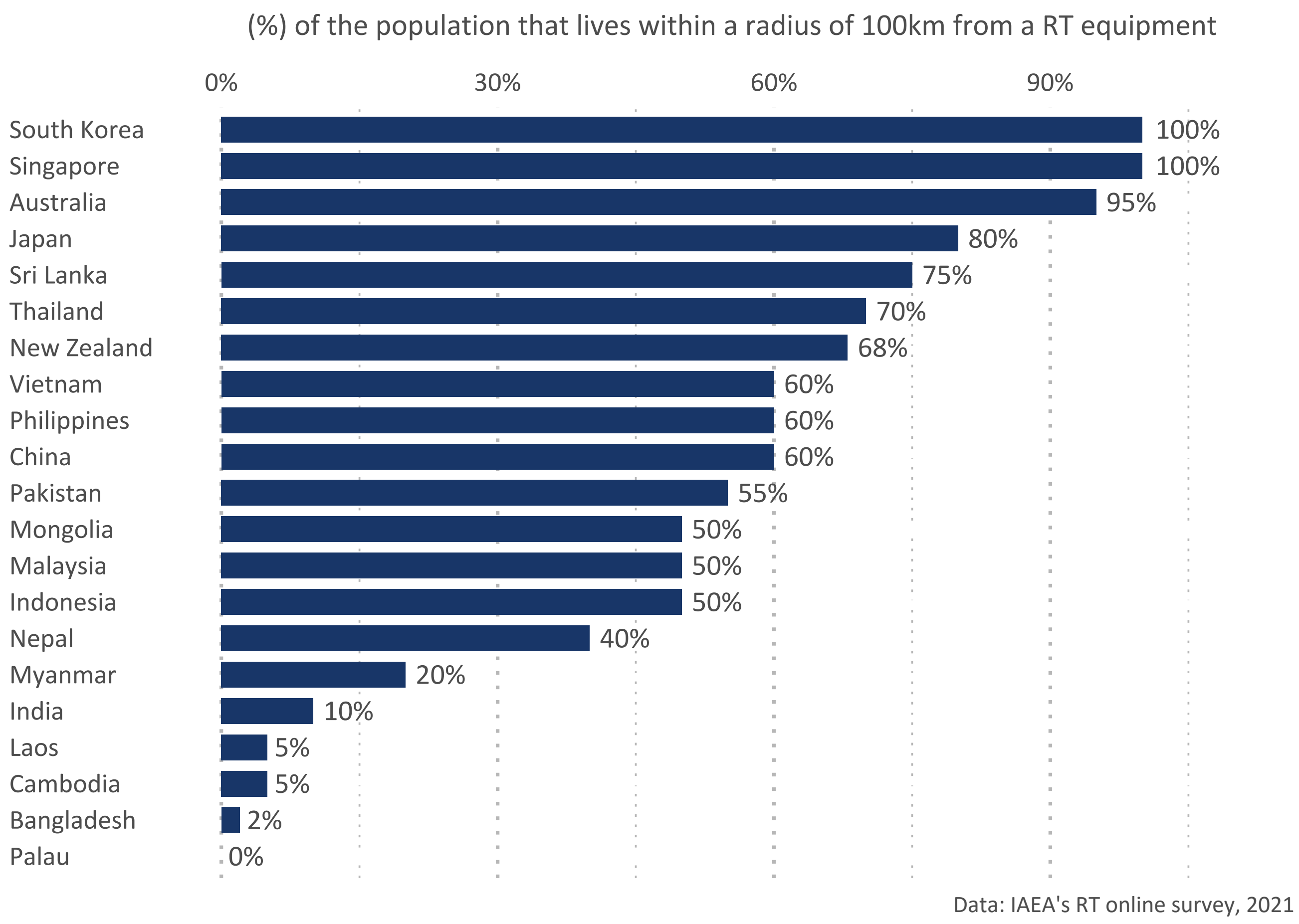
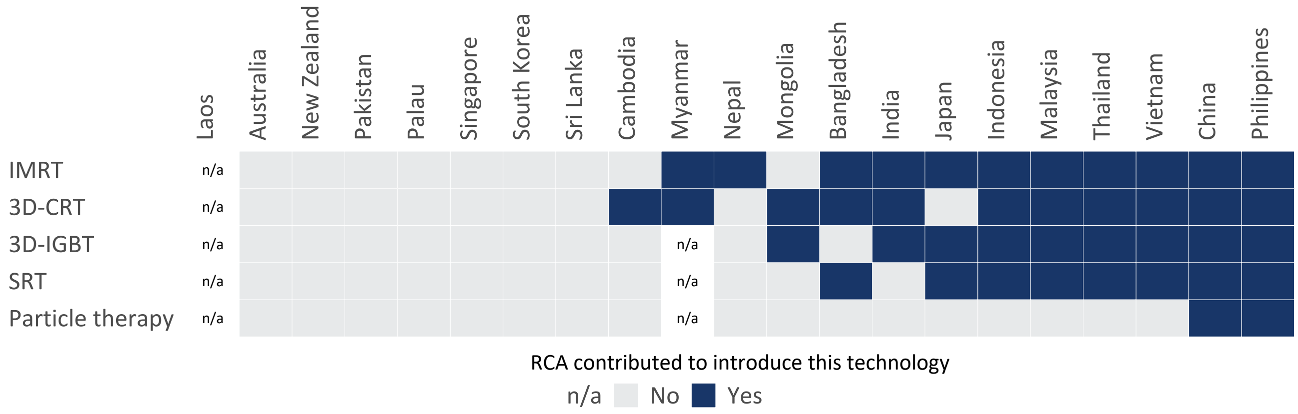


Figure 19: Approximate proportion of the population that lives within a radius of 100km from radiotherapy equipment



Data: IAEA's RT online survey, 2021

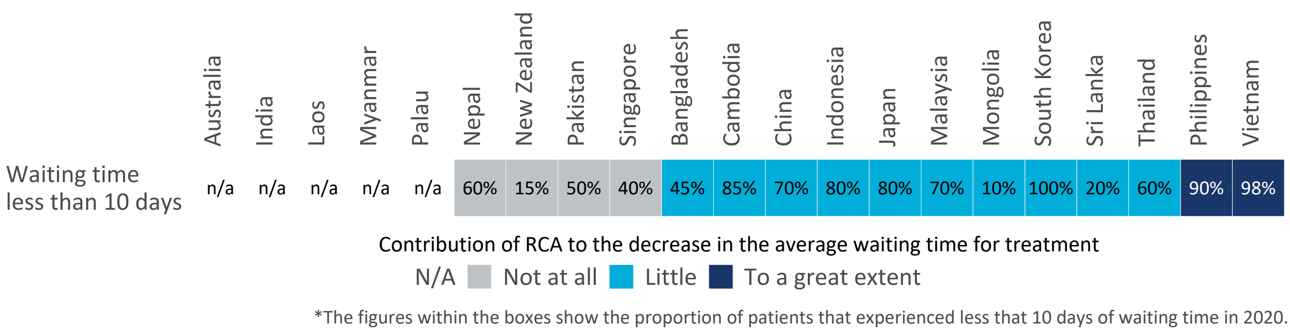
Figure 20: Contribution of RCA to introduction of radiotherapy technologies

In this chart, the acronyms stand for: Intensity-Modulated Radiation Therapy (IMRT), 3-Dimensional Conformal Radiation Therapy (3D-CRT), 3-Dimensional Image-Guided Brachytherapy (3D-IGBT), and Stereotactic Body Radiation Therapy (SRT).

Contribution of RCA to increasing access to quality radiotherapy

This section looks at the extent to which the RCA has contributed to increased access to quality radiotherapy. Figure 20 shows that the RCA contributed to the introduction of radiotherapy technologies in 13 of the State Parties.

Figure 21 shows each State Party respondent's assessment of the RCA's contribution to the reduction of waiting times. Twelve of the State Parties reported that the RCA contributed to any extent to the decrease in the average waiting time for treatment.



Data: IAEA's RT online survey, 2021

Figure 21: Contribution of RCA to reduction in average waiting time for treatment

Australia, India, Laos, Myanmar, and Palau did not report information about waiting times in the online survey.

Criterion 3: Increased life span and quality of life

The aim of this section is to understand the extent to which participating in the RCA has enabled State Parties to:

- Increase local 5-year tumour control rates
- Increase 5-year survival rates.

Sub-criterion	Evidence	Finding
Increase in local control or survival data	Approximate average 5-year local control rate in 2020 (average across all types of cancer)	54.7%
Increase in local control or survival data	Increase in the approximate 5-year local control rate in the period 2000-2020	15.6 percentage points improvement
Increase life-years	Approximate average 5-year survival rate in 2020 (average across all types of cancer)	55%
Increase life-years	Increase in the approximate 5-year survival rate in the period 2000-2020	14 percentage points improvement

Table 3: Key evidence for criterion 3: Increased life span and quality of life

Criterion 3.1 Increase in local control

Local control is defined as a complete tumour clearance at the primary site that has received treatment such as radiotherapy. The 5-year local control rate is the proportion of patients that retain the status of clear tumour clearance in the primary site after five years, as a percentage of all patients in the relevant patient population.

The average 5-year local control rate improved for all but one of the State Parties that reported information on this indicator (Figure 22). The average 5-year local control rate across all State Parties improved from 39 per cent to 55 per cent over the 20-year period.

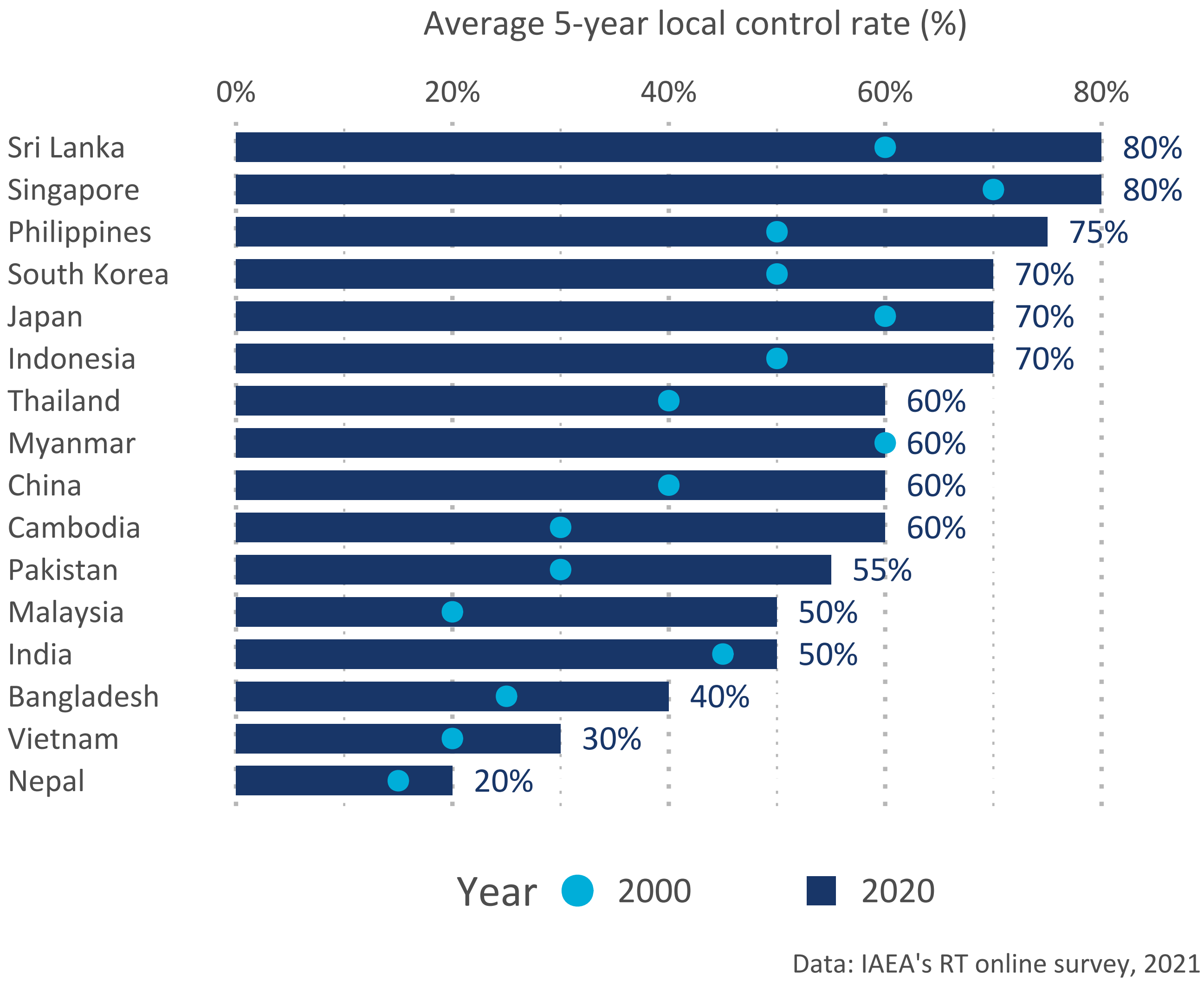


Figure 22: Approximate average 5-year local tumour control rate by State Party 2000 and 2020

Australia, Laos, Mongolia, New Zealand, and Palau did not report information about the average 5-year control rates in the online survey.

Criterion 3.2 Increased life-years

As can be seen in Figure 23, the average survival rate increased for all State Parties that reported this information in the online survey. From 2000 to 2020 the approximate average 5-year survival rate across all types of cancer increased from 41 per cent in 2000 to 55 per cent in 2020.

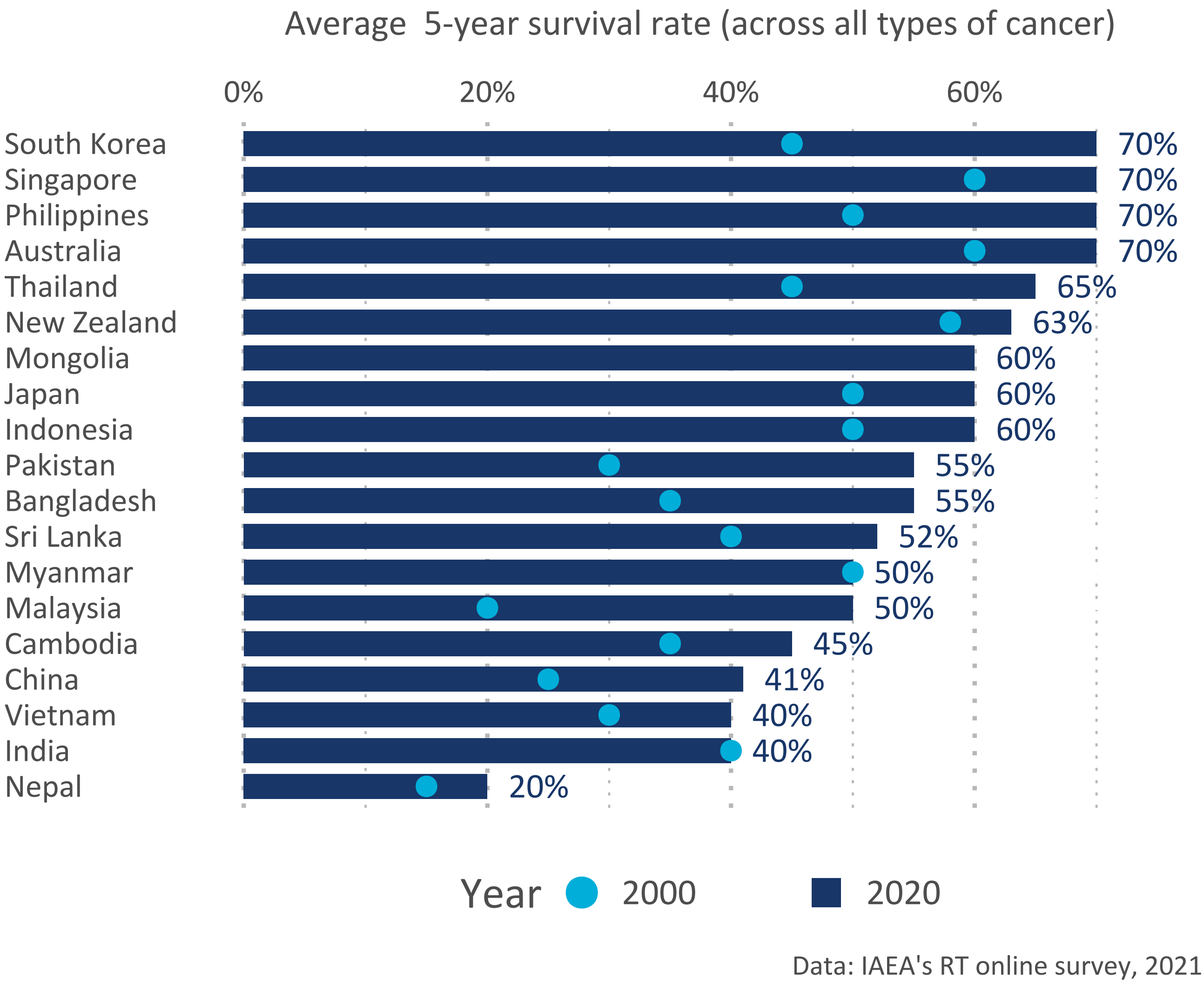


Figure 23: Approximate average 5-year survival rate by State Party 2000 and 2020

Laos did not provide information about average 5-year survival rates in the online survey.

Contribution of RCA on increasing life span

This section summarises State Party feedback on the extent to which the radiotherapy RCA has contributed to increase life span and quality of life of patients treated using radiotherapy facilities.

Figure 24 shows the extent to which the RCA contributed to the increase in the 5-year survival and control rates between 2000 and 2020.

	Australia	Laos	Mongolia	Myanmar	Palau	New Zealand	India	Pakistan	Singapore	Thailand	Cambodia	Indonesia	Japan	South Korea	Bangladesh	Nepal	China	Philippines	Sri Lanka	Vietnam	Malaysia
Control rate	n/a	n/a	n/a	60%	n/a	n/a	50%	55%	80%	60%	60%	70%	70%	70%	40%	20%	60%	75%	80%	30%	50%
Survival rate	70%	n/a	60%	50%	n/a	63%	40%	55%	70%	65%	45%	60%	60%	70%	55%	20%	41%	70%	52%	40%	50%

RCA impact to increase 5-year survival and control rates between 2000 and 2020

n/a; No impact; Small; Moderate; Significant; Large

The figures within the boxes show the average 5-year control and survival rates reported by the GPs in 2020.

Data: IAEA's RT online survey, 2021

Figure 24: RCA contribution to increases in 5-year survival and control rates by State Party

Australia, Laos, Mongolia, Myanmar and Palau did not provide this information in the online survey.

Supplementary table: Waiting times in 2000 and 2020

The following table provides additional detail on the proportion of patients treated within waiting times of less than 5 days, 5–6 days, 7–9 days, and 10 days or more. Summary analysis is provided in Figures 17 and 18 above.

Country	Waiting time	2000	2020	Change
Australia	Less than 5 days			
Australia	Between 5 and 6 days			
Australia	Between 7 and 9 days			
Australia	10 days or more			
Australia	N/A because RT treatment was not available			
Bangladesh	Less than 5 days	40%	10%	-30%
Bangladesh	Between 5 and 6 days	25%	15%	-10%
Bangladesh	Between 7 and 9 days	15%	20%	5%
Bangladesh	10 days or more	20%	55%	35%
Bangladesh	N/A because RT treatment was not available	0%	0%	0%
Cambodia	Less than 5 days	5%	30%	25%
Cambodia	Between 5 and 6 days	20%	30%	10%
Cambodia	Between 7 and 9 days	30%	25%	-5%
Cambodia	10 days or more	45%	15%	-30%
Cambodia	N/A because RT treatment was not available	0%	0%	0%
China	Less than 5 days	10%	30%	20%
China	Between 5 and 6 days	20%	20%	0%
China	Between 7 and 9 days	20%	20%	0%
China	10 days or more	50%	30%	-20%
China	N/A because RT treatment was not available	0%	0%	0%
India	Less than 5 days	0%		
India	Between 5 and 6 days	0%		
India	Between 7 and 9 days			
India	10 days or more			
India	N/A because RT treatment was not available	0%		
Indonesia	Less than 5 days	5%	20%	15%
Indonesia	Between 5 and 6 days	10%	20%	10%
Indonesia	Between 7 and 9 days	35%	40%	5%
Indonesia	10 days or more	50%	20%	-30%
Indonesia	N/A because RT treatment was not available			
Japan	Less than 5 days	20%	30%	10%
Japan	Between 5 and 6 days	10%	30%	20%
Japan	Between 7 and 9 days	30%	20%	-10%
Japan	10 days or more	40%	20%	-20%
Japan	N/A because RT treatment was not available	0%	0%	0%
Laos	Less than 5 days			
Laos	Between 5 and 6 days			
Laos	Between 7 and 9 days			
Laos	10 days or more			
Laos	N/A because RT treatment was not available			
Malaysia	Less than 5 days	20%	20%	0%
Malaysia	Between 5 and 6 days	20%	25%	5%
Malaysia	Between 7 and 9 days	20%	25%	5%
Malaysia	10 days or more	20%	25%	5%
Malaysia	N/A because RT treatment was not available	20%	5%	-15%
Mongolia	Less than 5 days	100%	0%	-100%
Mongolia	Between 5 and 6 days	0%	0%	0%

Table 4: Proportion of patients treated by waiting time and State Party 2000 and 2020

Country	Waiting time	2000	2020	Change
Mongolia	Between 7 and 9 days	0%	10%	10%
Mongolia	10 days or more	0%	90%	90%
Mongolia	N/A because RT treatment was not available	0%	0%	0%
Myanmar	Less than 5 days	0%		
Myanmar	Between 7 and 9 days			
Myanmar	10 days or more		100%	
Nepal	Less than 5 days	10%	10%	0%
Nepal	Between 5 and 6 days	20%	20%	0%
Nepal	Between 7 and 9 days	20%	30%	10%
Nepal	10 days or more	50%	40%	-10%
Nepal	N/A because RT treatment was not available	0%	0%	0%
New Zealand	Less than 5 days	3%	3%	0%
New Zealand	Between 5 and 6 days	4%	4%	0%
New Zealand	Between 7 and 9 days	8%	8%	0%
New Zealand	10 days or more	85%	85%	0%
Pakistan	Less than 5 days	30%	10%	-20%
Pakistan	Between 5 and 6 days	20%	20%	0%
Pakistan	Between 7 and 9 days	30%	20%	-10%
Pakistan	10 days or more	20%	50%	30%
Pakistan	N/A because RT treatment was not available	0%	0%	0%
Palau	Less than 5 days	0%	0%	0%
Palau	Between 5 and 6 days	0%	0%	0%
Palau	Between 7 and 9 days	0%	0%	0%
Palau	10 days or more	0%	0%	0%
Palau	N/A because RT treatment was not available	0%	0%	0%
Philippines	Less than 5 days	15%	30%	15%
Philippines	Between 5 and 6 days	20%	30%	10%
Philippines	Between 7 and 9 days	50%	30%	-20%
Philippines	10 days or more	15%	10%	-5%
Philippines	N/A because RT treatment was not available	0%	0%	0%
Singapore	Less than 5 days	20%	20%	0%
Singapore	Between 5 and 6 days	10%	10%	0%
Singapore	Between 7 and 9 days	10%	10%	0%
Singapore	10 days or more	60%	60%	0%
Singapore	N/A because RT treatment was not available	0%	0%	0%
South Korea	Less than 5 days	30%	100%	70%
South Korea	Between 5 and 6 days	0%	0%	0%
South Korea	Between 7 and 9 days	50%	0%	-50%
South Korea	10 days or more	20%	0%	-20%
South Korea	N/A because RT treatment was not available	0%	0%	0%
Sri Lanka	Less than 5 days	0%	0%	0%
Sri Lanka	Between 5 and 6 days	0%	0%	0%
Sri Lanka	Between 7 and 9 days	20%	20%	0%
Sri Lanka	10 days or more	80%	80%	0%
Sri Lanka	N/A because RT treatment was not available	0%	0%	0%
Thailand	Less than 5 days	2%	10%	8%
Thailand	Between 5 and 6 days	8%	20%	12%
Thailand	Between 7 and 9 days	10%	30%	20%
Thailand	10 days or more	80%	40%	-40%
Vietnam	Less than 5 days	50%	60%	10%
Vietnam	Between 5 and 6 days	30%	30%	0%
Vietnam	Between 7 and 9 days	12%	8%	-4%
Vietnam	10 days or more	6%	2%	-4%
Vietnam	N/A because RT treatment was not available	2%	0%	-2%

Annex F: Economic Analysis

Summary of findings

We estimated the economic impacts in RCA State Parties of radiotherapy RCA projects between 2000 and 2020. Based on results from our survey of radiotherapy experts in RCA State Parties, there is strong evidence that the RCA helped to improve the quantity and quality of radiotherapy treatments provided to cancer patients in State Parties. We therefore assume that the number of people treated with radiotherapy in State Parties between 2000 and 2020 would have been lower in the absence of the RCA, and this difference in the number of people treated generated socio-economic benefits and costs in State Parties that we have estimated.

We use three alternative methods to value the benefits generated by the RCA as a form of sensitivity analysis. The reasons for using these alternative methods are discussed below. Under these methods and relative to estimated counterfactual outcomes in RCA State Parties between 2000 and 2020 if there was no RCA, under our baseline assumptions we estimate that on average each one EUR of economic costs directly or indirectly associated with the RCA generated the following alternative estimates of benefits:

- EUR 0.55 of pure economic benefits measured in terms of increased gross domestic product (GDP) in RCA State Parties *or*
- EUR 1.31 of socio-economic benefits accounting for both increased GDP and the social value of additional health-adjusted life-years of cancer patients treated with radiotherapy who received a survival benefit. This implies that the social value of additional health-adjusted life years is EUR 0.76 (i.e. 1.31 – 0.55) *or*
- EUR 1.04 of socio-economic benefits based on international estimates of willingness to pay for additional health-adjusted life-years of cancer patients treated with radiotherapy who received a survival benefit.

Our estimates are conservative in that we have considered only impacts of the RCA on the number of cancer patients treated between 2000–2020, and benefits in the form of increased five-year survival rates. We also expect additional benefits from improved quality of treatment, plus quality of life benefits from improved local control of tumours and better palliative care outcomes for some patients. Moreover, the modelled results estimate the value of the RCA's contribution under real-world limitations to wider (non-radiotherapy) components of medical care in middle income countries, whereas the potential value of RCA activities, absent these constraints, would be greater in some RCA State Parties.

Overview of our economic evaluation methodology

Objectives of the economic analysis

We developed a quantitative model to estimate the socio-economic impacts in RCA State Parties attributable to radiotherapy RCA activities from 2000 to 2020 (inclusive). The principal benefits generated by radiotherapy treatment arise from improvements in human health. Although radiotherapy has other uses, the RCA, and therefore this study, focuses on use of radiotherapy to treat cancer patients. By helping such patients to live longer and improving their quality of life, radiotherapy treatments generate additional economic activity and wider socio-economic (wellbeing) benefits to patients, their families, and communities. Accordingly, our analysis includes estimates of:

- economic and wider social benefits enabled by radiotherapy RCA activities in State Parties;
- economic costs attributable to radiotherapy RCA activities in State Parties , including in-kind contributions to the RCA, opportunity costs, and indirect costs associated with participation in the RCA; and
- direct expenditure by the IAEA on radiotherapy RCA activities

This study assesses the economic impacts of the RCA, including both measured economic activity and wider social benefits. Therefore, the analysis focuses on the incremental economic impacts that can be attributed to improved *collaboration* in radiotherapy technologies among RCA State Parties, as enabled by the RCA. We did not estimate the overall benefits and costs of all radiotherapy treatment activity in RCA State Parties. Such benefits are expected to be larger than the incremental impacts of the RCA on adoption and use of radiotherapy, but most such benefits cannot be attributed to the RCA.

Our analysis uses a similar framework to Atun *et al* (2015).[29] We seek to estimate incremental increases in the number of cancer patients treated with radiotherapy in RCA State Parties attributable to RCA activities. The benefits and costs of these additional treatments are then quantified and compared. The economic analysis is also targeted at assessing the RCA against the agreed evaluation rubric for economic value. This requires evaluating how likely it is that the RCA created more value than it consumed, i.e., whether break-even was achieved in terms of socio-economic benefits created compared to costs incurred.

Measuring economic impacts of the RCA

The economic performance of the radiotherapy RCA over the period from 2000 to 2020 was quantified in two different but complementary ways:

1. *Incremental cost effectiveness:* The estimated ratio of human health benefits delivered by the radiotherapy RCA to costs attributable to the radiotherapy RCA. Benefits were measured in terms of additional health-adjusted life-years of cancer patients treated with radiotherapy.[30]
2. *Overall net economic benefits:* The estimated present value of additional benefits delivered by the radiotherapy RCA relative to the incremental costs attributable to the radiotherapy RCA (expressed as a benefit-cost ratio).

As described below, we use three different methods for measuring net economic benefits, so overall we evaluate the economic performance of the RCA in four ways.

Cost effectiveness

Cost-effectiveness is a standard approach to economic evaluation of health interventions[31] and is based on the ratio of health benefits (measured in natural or physical units, such as additional life-years gained) to costs. Cost effectiveness avoids the need to put a monetary value on human health benefits, and the estimated cost-effectiveness ratio for the radiotherapy RCA can be compared to benchmarks for other health interventions to assess the relative effectiveness of the RCA.

Cost-effectiveness does not allow the direct comparison of benefits and costs of the RCA as benefits are measured in different units from costs. Our overall net socio-economic benefits analysis addresses this by measuring health benefits in monetary terms so these can be directly compared with costs. This enables us to calculate an estimated monetary return on the costs attributable to the RCA between 2000 and 2020. However, there are some challenges with valuing health benefits in monetary terms, as explained below.

Net economic benefits (benefit-cost ratio)

Estimating net economic benefits of the RCA requires putting a monetary value on human health benefits of the improvements to radiotherapy treatment enabled by the

29 www.thelancet.com/journals/lanonc/article/PIIS1470-2045(15)00222-3/fulltext

30 Our approach to quality-adjustment in the estimated benefits of radiotherapy treatment is simple and broadly accounts for the fact that cancer patients may experience lower quality of life than people in full health, on average. This is discussed further below.

31 Drummond *et al* (2015).

RCA, so that these benefits can be directly compared to costs. One way to do this is to use annual GDP per capita as a measure of the value of a health-adjusted life-year in a State Party. Annual GDP per capita directly measures the additional economic activity associated with an additional year of life (on average). A multiplier can also be applied to GDP to reflect the broader social value of additional health-adjusted life-years.

These GDP-based approaches are straightforward but imply vastly different values of life-years across RCA State Parties due to differences in annual GDP per capita. One consequence is that the estimated returns on investment in radiotherapy facilities based on this approach may be greatest in high-income countries, but the greatest needs for additional facilities are in lower-income countries where not all cancer patients who could benefit from radiotherapy are able to be treated due to capacity constraints (Atun *et al,* 2015). Among the objections to this approach are the argument that the value of a human life is poorly represented by GDP per capita, and that a human life should be valued equally across RCA State Parties regardless of variations in national income.

Alternative approaches, that are not directly proportional to GDP, try to estimate people's willingness to pay for additional life-years, but this is not straightforward as there is no market price for human life-years. Instead, willingness to pay for additional life-years needs to be estimated by indirect methods such as surveys, or by inferring the 'value of a statistical life' (VSL) from other market outcomes such as wage differentials for risky occupations. A recent review of the literature found that the estimated value of life-years varies greatly depending on where and how it is measured (McDougall *et al,* 2020).

Given these challenges, we valued health benefits of the radiotherapy RCA in three different ways in our benefit-cost ratio (BCR) calculations, as a form of sensitivity analysis:

1. *Pure economic benefits:* This includes only the economic activity-related benefits of additional health-adjusted life-years attributed to the radiotherapy RCA, by valuing each incremental health-adjusted life-year at the value of annual real GDP per capita in the relevant year and country.[32]
2. *Local social benefits:* An estimate of economic activity-related benefits plus local willingness to pay for additional health-adjusted life-years attributed to the radiotherapy RCA, by valuing each life-year at a multiple of annual real GDP per capita in the relevant year and country.[33] Based on values in the literature (Jamison *et al* 2013) we applied a multiple of 2.4 times annual real GDP per capita, with sensitivity tests of 1.9 and 2.9.[34]
3. *International social benefits:* An estimate of the overall value of additional health-adjusted life-years attributed to the radiotherapy RCA by using a constant average value per life year across all countries. We use an estimate of EUR 27 000 per life year (based on McDougall *et al,* 2020), with sensitivity tests of EUR 20 000 and EUR 34 000 (approximately +/- 10 per cent). This avoids issues arising from valuing life-years differently in different countries, but there is more uncertainty about the appropriate average value of a life-year when that value is not directly linked to GDP.

32 Atun *et al* (2015) refer to this as the “human capital” approach to valuing benefits of radiotherapy.

33 Atun *et al* (2015) refer to this as the “full income” approach to valuing benefits of radiotherapy.

34 The value of 2.4 was calculated as a population-weighted average of the GDP multiples provided in table A3.10 (column c) of Jamison *et al* (2013).

High-level effects of the RCA on economic activity and wellbeing

The current priorities of the RCA in relation to promoting human health are to:[35]

- Strengthen cancer management programmes in RCA State Parties, including training of radiation oncologists, medical physicists and technologists.
- Simplify and harmonise protocols on diagnostic imaging and for treatment/palliation planning and radiotherapy treatment.
- Assist in the development and utilisation of radio-labelled pharmaceuticals for imaging and treatment.
- Strengthen nuclear medicine to effectively diagnose and assess the extent of cardiovascular diseases, diabetes, mosquito-based diseases, and to monitor cancer treatment effects.

Our socio-economic analysis focuses on treatment of cancer patients as this is the main application of radiotherapy and is a potential source of significant benefits.

Health and economic benefits of the RCA therefore come from any improvements in the quality and/or quantity of cancer treatments provided by radiotherapy facilities in State Parties that can be attributed to the RCA. The RCA enables more patients per year to be treated and/or to provide more effective treatments to those who are treated. While the radiotherapy RCA does not directly invest in radiotherapy facilities, it may also enable State Parties to expand their radiotherapy facilities by giving them capabilities to use such facilities effectively. The RCA may also enable investments in radiotherapy facilities to be made from other funding sources, by developing the skills and knowledge necessary to justify such investments.

When radiotherapy enables people to live longer and better-quality lives, this directly generates some economic activity associated with the productive work and consumption activities of people who are successfully treated. In addition to these benefits in terms of measured economic activity, socio-economic benefits may also arise in the form of increased wellbeing of patients, their families,

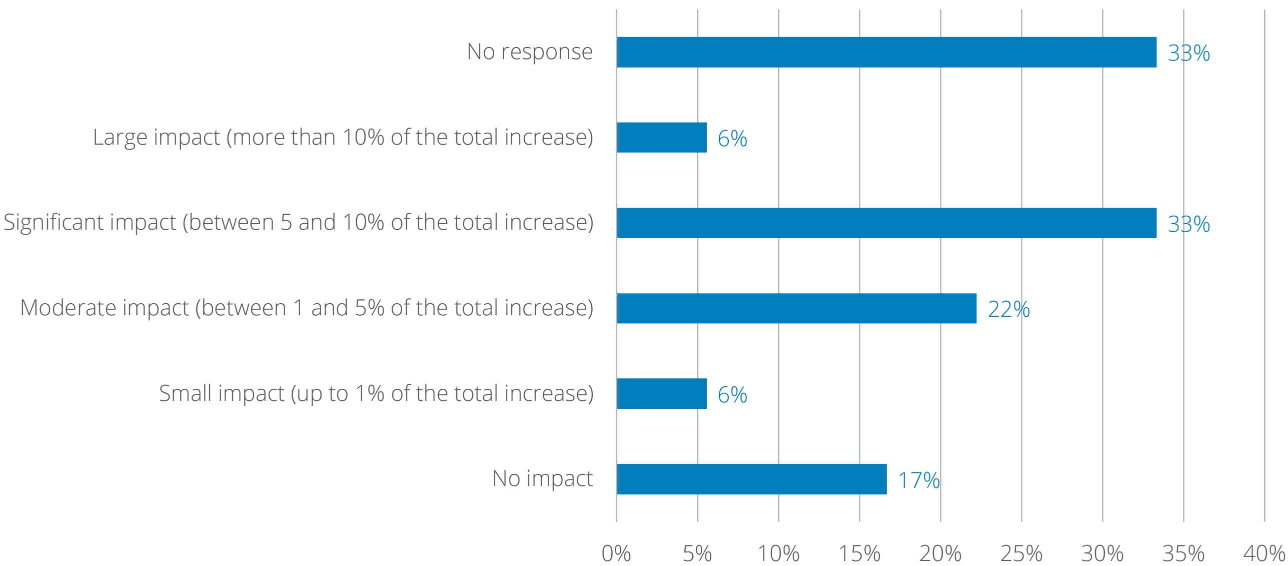


Figure 25: Reported contribution of the RCA to the increase in the number of people treated with radiotherapy between 2000 and 2020. Source: Online survey of experts in RCA State Parties.

35 IAEA, *RCA Medium Term Strategy 2018-2023,* section C.2.2.

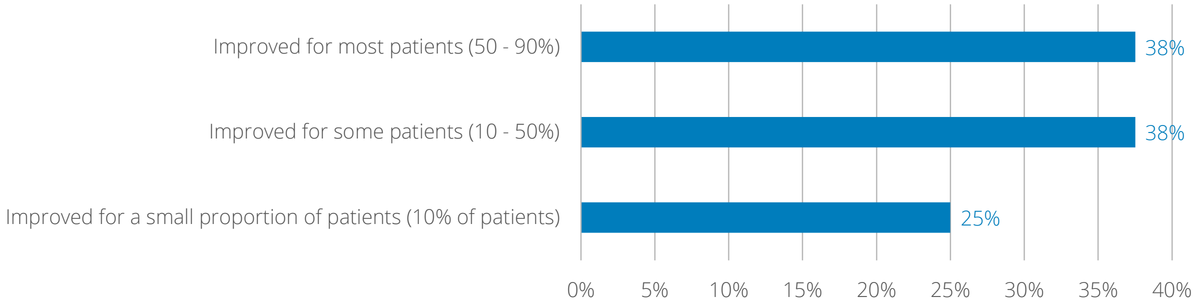


Figure 26: Reported impacts of the RCA on the quality of treatment among State Parties where the RCA was reported to improve treatment quality. Source: Online survey of experts in State Parties.

and society more generally. Our analysis seeks to capture both types of benefits.

In most RCA State Parties, the number of people treated with radiotherapy has increased significantly over time. Among State Parties that responded to our survey, the reported number of cancer patients treated with radiotherapy increased from around 625 000 in 2000 to around 1.4 million in 2020, a compound annual growth rate of 4.0 per cent. Figure 25 shows responses from experts in RCA State Parties to our survey question about the contribution of the RCA to this growth in the number of patients treated. Half of State Parties reported that the RCA had an impact, with most of those reporting that between 1 per cent and 10 per cent of the increase could be attributed to the RCA.

In addition, 76 per cent of respondents from State Parties tates indicated that the RCA led to an improvement in the quality of radiotherapy treatment. Of the State Parties that reported a quality improvement attributable to the RCA, 38 per cent reported that quality improved for more than half of patients, and a further 38 per cent reported that quality improved for 10 per cent to 50 per cent of patients (Figure 26).

In terms of outcomes for cancer patients treated with radiotherapy, two-thirds of experts from State Parties reported that the RCA contributed to an improvement in the local control rate[36] for cancer patients

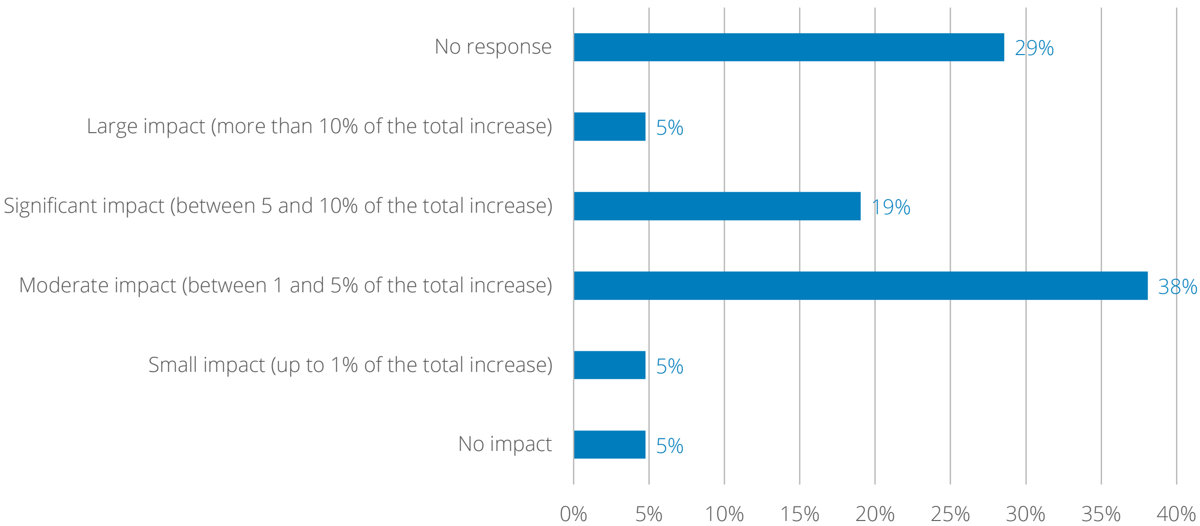


Figure 27: Reported contribution of the RCA to the change in the local control rate for cancer patients in State Parties. Source: Online survey of experts in RCA State Parties.

36 Local control of cancer refers to stopping growth of tumours at the original site.

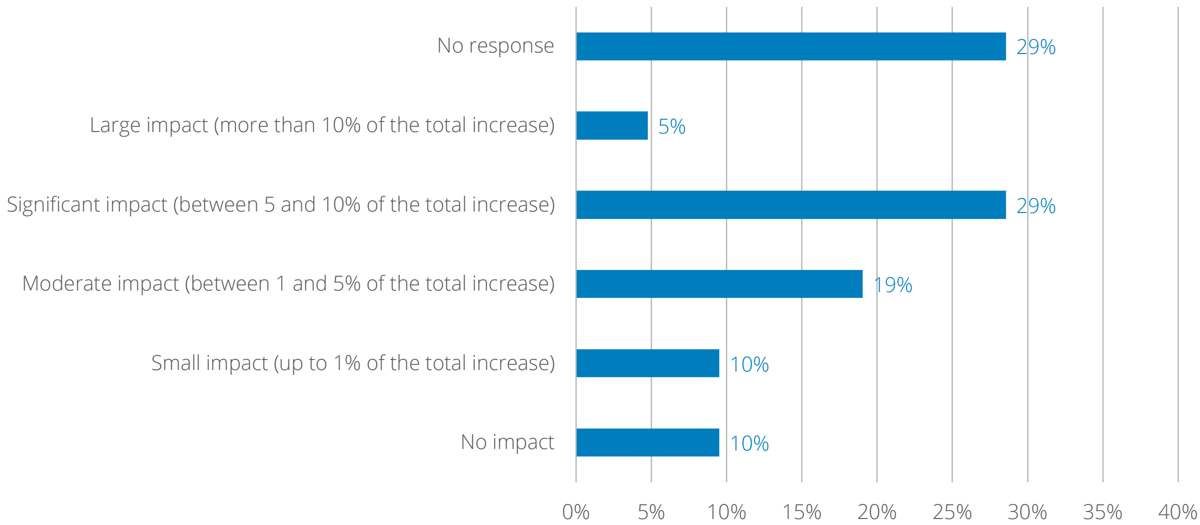


Figure 28: Reported contribution of the RCA to the change in five-year overall survival rates for cancer patients in State Parties.
Source: Online survey of experts in RCA State Parties.

(Figure 27) and around 60 per cent reported that the RCA contributed to an improvement in five-year overall survival rates (Figure 28).

Additional supporting evidence about the that improvements in the quantity and quality of radiotherapy treatment in RCA State Parties is given in the four case studies reported above:

- By participating in the RCA, Bangladesh has received technical assistance to upgrade the skills of its radiotherapy specialists, and support for the expansion and strengthening of its radiotherapy facilities. Increased numbers of well-trained staff, radiotherapy facilities and equipment have increased the accessibility of radiotherapy and the number of cancer patients treated with radiotherapy increased by more than 20 times between 2000 and 2020.
- Indonesia's participation in the radiotherapy programme of the RCA contributed to strengthening education and training in radiation oncology, and led to increased investment in radiotherapy technology. The RCA empowered sharing of best practices among radiation oncology experts and capacity-building activities contributed toan increase in the number of certified radiotherapy medical professionals.
- Participation in the RCA helped Mongolia to modernize its radiotherapy equipment and increased opportunities for training in radiotherapy. Accessibility of radiotherapy treatment for cancer patients improved with the introduction of more advanced technologies and strengthened technical competencies of radiotherapy medical staff. Collaboration under the RCA also increased awareness and knowledge of the general public about the benefits and importance of radiotherapy treatment for cancer, which increased the number of patients who are willing to seek such treatment.
- Thailand's participation in the RCA contributed to strengthening its radiation oncology workforce and accelerated the implementation of sophisticated radiotherapy services. Participation in the RCA also helped to improve access to new radiotherapy technologies and increased the quality and access to treatment, leading to improved treatment for cancer patients.

Taken together, these survey results provide good evidence that the RCA has led to an increase in both the quantity and quality of radiotherapy treatments for cancer patients in RCA State Parties. However, there is some uncertainty about the extent to which these changes can be attributed to RCA activities and we therefore carry out sensitivity analysis that accounts for uncertainty about the impact of the RCA on radiotherapy treatment in RCA State Parties. For simplicity, our analysis below focuses on economic impacts of the increased quantity of treatment, however we note that increased treatment quality may also generate economic benefits.

Modelling socio-economic benefits and costs of the RCA

Modelled scenarios

Impacts of the radiotherapy RCA were estimated using a retrospective cost-effectiveness analysis (CEA) and retrospective cost-benefit analysis (CBA), as described above. Both methods require estimates of benefits and costs across all State Parties that can be plausibly attributed to RCA activities between 2000 and 2020. This was done by comparing two scenarios:

1. *Factual scenario:* Actual outcomes relating to radiotherapy treatment in RCA State Parties between 2000 and 2020 (i.e., outcomes that occurred under the RCA).
2. *Counterfactual scenario:* A hypothetical scenario of radiotherapy treatment outcomes that would have occurred in RCA State Parties between 2000 and 2020 in the absence of the RCA.

These two scenarios were compared for each State Party individually, however this study only aims to estimate the aggregate economic impacts of the RCA. Benefits and costs attributable to the RCA come from the difference in the volume of actual radiotherapy treatments provided for cancer patients versus the volume of treatments in the hypothetical counterfactual, in each year for each RCA State Party.

The economic analysis is based on the *difference* between the factual and counterfactual scenarios, and to simplify the analysis we only model *incremental* benefits and costs in the factual scenario relative to the counterfactual. We do not try to estimate total benefits and costs of radiotherapy treatment in State Parties in either the factual or counterfactual scenarios. These total benefits and costs will be considerably larger than the incremental effects that we have estimated.

Modelling benefits of RCA activities

The socio-economic benefits of RCA activities in State Parties were modelled as follows:

1. The number of people diagnosed with cancers commonly treated with radiotherapy was estimated in each year using data on cancer incidence rates by age, and the population structure of each RCA State Party. Of these people, the number treated with radiotherapy in each year was estimated based on recommended radiotherapy utilisation rates and actual radiotherapy treatment capacity in each State Party.
2. The impact of the RCA on radiotherapy treatment volumes was estimated by estimating the number of people who would have been treated in each State Party in each year in the counterfactual scenario, based on information provided by experts in State Parties about the impact of the RCA on radiotherapy treatment volumes.
3. For the additional people who were treated under the RCA in each State Party and in each year (who would not have been treated without the RCA), benefits in terms of additional health-adjusted life-years and costs associated with the additional treatment were estimated.

4. Monetary values were assigned to the benefits in terms of additional health-adjusted life-years that can be attributed to the RCA, so that BCRs can be calculated. This was done under the three different approaches described above.

Each of these steps are described in more detail below.

Estimated cancer and radiotherapy treatment volumes in RCA State Parties

Our analysis focuses on ten types of cancer that are commonly treated with radiotherapy (Table 5). The selection of these cancer types was validated by IAEA experts. For these types, we estimated the number of people in each RCA State Party diagnosed with cancer in each year using cancer incidence rates from the World Health Organisation.[37] Cancer incidence rates by cancer type, age group, and year were applied to the population structure in each RCA State Party to estimate the number of people newly diagnosed each year.[38]

The number of cancer patients treated with radiotherapy in each RCA State Party in each year was estimated based on:

- The optimal radiotherapy utilisation rate and average number of radiotherapy treatment fractions required for each type of cancer (Table 5).
- The estimated capacity to provide radiotherapy treatment in each year in each State Party, based on the number of available radiotherapy machines and the estimated treatment capacity (radiotherapy fractions) provided by each machine.

Tumour type	Optimal radiotherapy utilisation rate	Average radiotherapy fractions per course	5-year overall survival benefit
Breast	87%	16	2%
Cervix	71%	21	20%
Colorectal	19%	23	2%
Head and neck	74%	22	20%
Lung	77%	16	6%
Oesophagus	71%	15	2%
Prostate	58%	28	1%
Stomach	27%	19	1%
Brain/CNS	80%	29	11%
Corpus uteri	32%	20	6%

Table 5: Characteristics of tumours commonly treated with radiotherapy. Source: Atun et al (2015), except the figures for brain/CNS and corpus uteri tumours which were obtained from Barton et al (2013) and Hanna et al (2018).

37 See https://ci5.iarc.fr/Default.aspx.

38 Incidence rates are only available for Australia, China, India, Japan, South Korea, New Zealand, Philippines, and Thailand. Rates for remaining RCA member states are assumed to be the same as the most similar country within this set. Incidence rates from 2013 to 2020 are assumed to be the same as 2012 as no data is available after 2012.

The number of available radiotherapy treatment machines in each RCA State Party in each year was estimated from information provided in our online survey of experts in State Parties. Where suitable data on radiotherapy capacity was not provided in the survey, information from the IAEA's Directory of Radiotherapy Centres (DIRAC) was used instead.[39] Across all RCA State Parties, we estimate the total number of available radiotherapy machines in State Parties increased from 2 300 in 2000 to 4 573 in 2020 (Figure 29).

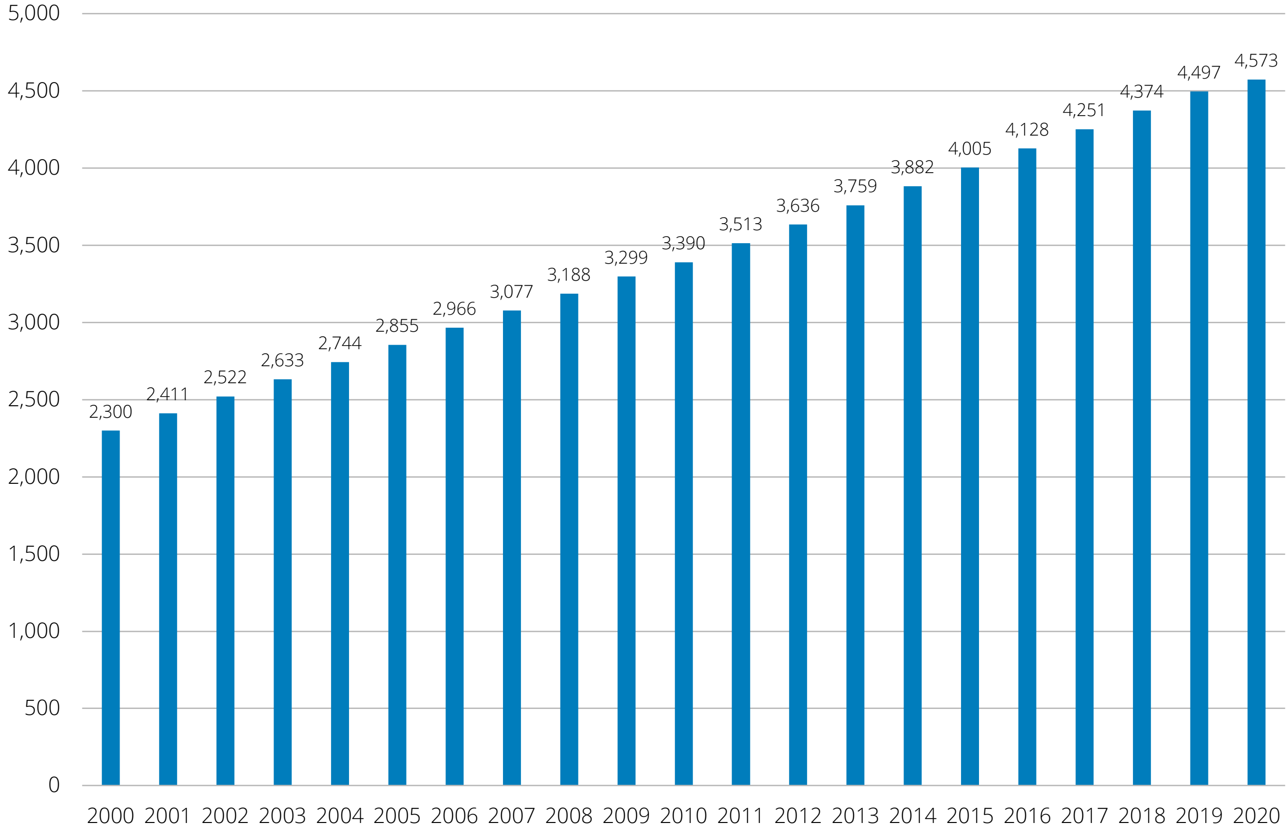


Figure 29: Estimated total number of operational radiotherapy treatment machines in RCA State Parties. Source: Estimated from online survey of experts in RCA State Parties or from IAEA DIRAC data if survey results were not provided.

39 www.iaea.org/resources/databases/dirac

Using estimates of the annual number of radiotherapy treatment fractions provided by each machine (Table 6 below), we estimated total radiotherapy treatment capacity in each year in each RCA State Parties.[40] In some State Parties, the available capacity was less than what was required to treat all patients with cancers that could be treated with radiotherapy. In such cases we assumed that treatment was constrained by available capacity. The corresponding estimates of cancer patients treated and untreated across all RCA State Parties are shown in Figure 30.[41] We estimate that only around 40 per cent of cancer patients who could benefit from radiotherapy receive treatment in RCA State Parties, which suggests that there are significant potential benefits from improving access to radiotherapy, as found by Atun *et al* (2015).

Income category	Treatment fractions per radiotherapy machine
High income	8 515
Upper middle income	10 592
Lower middle income	10 513

Table 6: Estimated annual radiotherapy treatment fractions per radiotherapy machine by country income category. Source: Calculated from data in Atun *et al* (2015, page 1167).

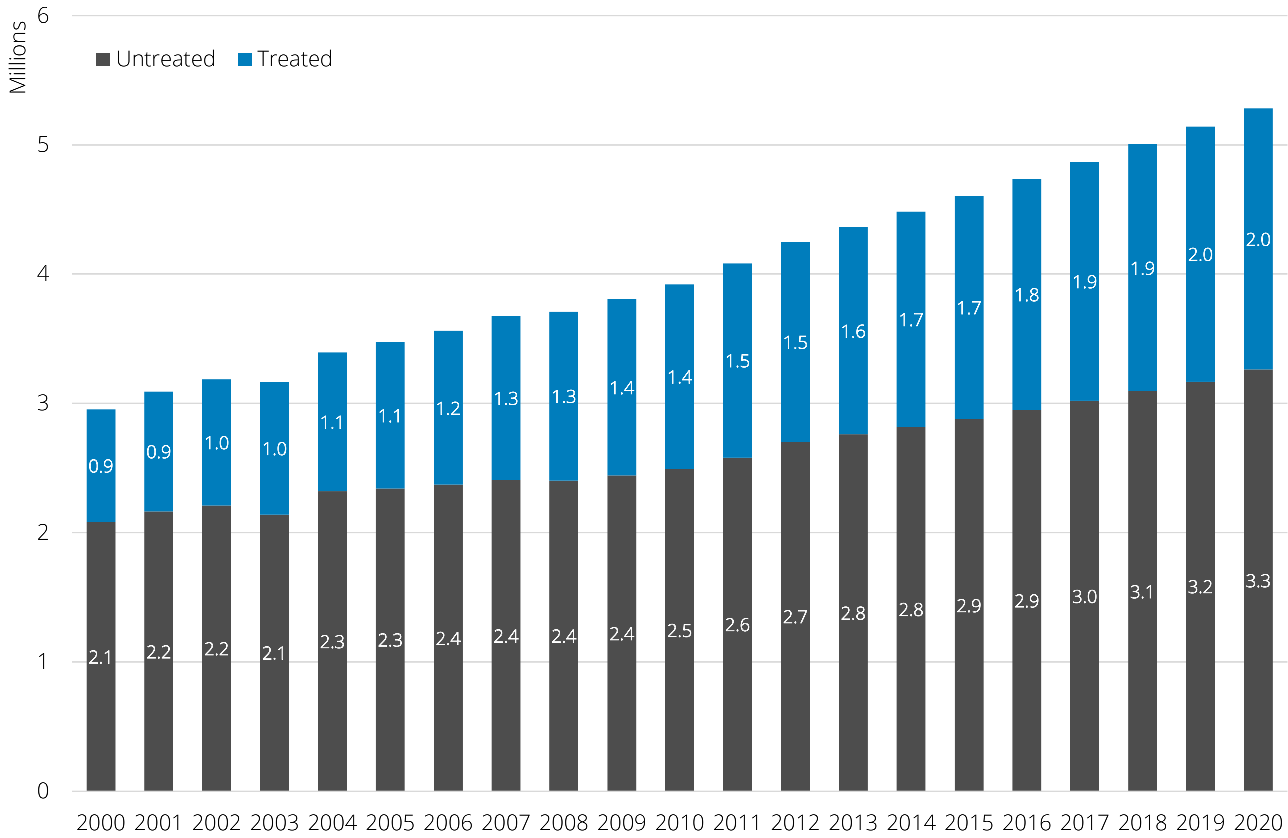


Figure 30: Estimated annual number of people diagnosed with cancers treatable with radiotherapy in RCA State Parties. Source: Calculated.

40 Radiotherapy machines in upper middle and lower middle income countries are assumed to provide more treatment fractions per year than in high income countries due to increased operating hours and more intensive utilisation.

41 Estimates of the number of cancer patients treated with radiotherapy in each member state were also adjusted to match information provided in our survey of experts about treatment volumes in 2020, if available.

Increased availability and use of radiotherapy

Across RCA State Parties, the estimated number of cancer patients treated with radiotherapy more than doubled between 2000 and 2020 (Figure 30 above). Respondents to our online survey were asked about the extent to which the RCA had contributed to any increase in radiotherapy treatment volumes in their country over this period (Figure 1 above). This information was used to estimate how many fewer patients would have been treated in each State Party in each year, in the absence of the RCA.

Figure 31 shows these estimates under our baseline assumptions. Across all State Parties, based on information provided by experts in our online survey, we estimate that the impact of the RCA on radiotherapy treatment volumes has increased over time, reaching 2.3 per cent of cancer patients treated with radiotherapy in 2020 under our baseline assumptions.[42] This corresponds to an estimated additional 45 000 patients treated with radiotherapy in 2020 who would not otherwise have been treated in the absence of the RCA. Given the uncertainty associated with the self-reported impacts of the RCA on radiotherapy treatment volumes by State Parties, we also test the sensitivity of our results to alternative assumptions about the number of additional patients treated that can be attributed to the RCA (see the last row of Table 10 below).

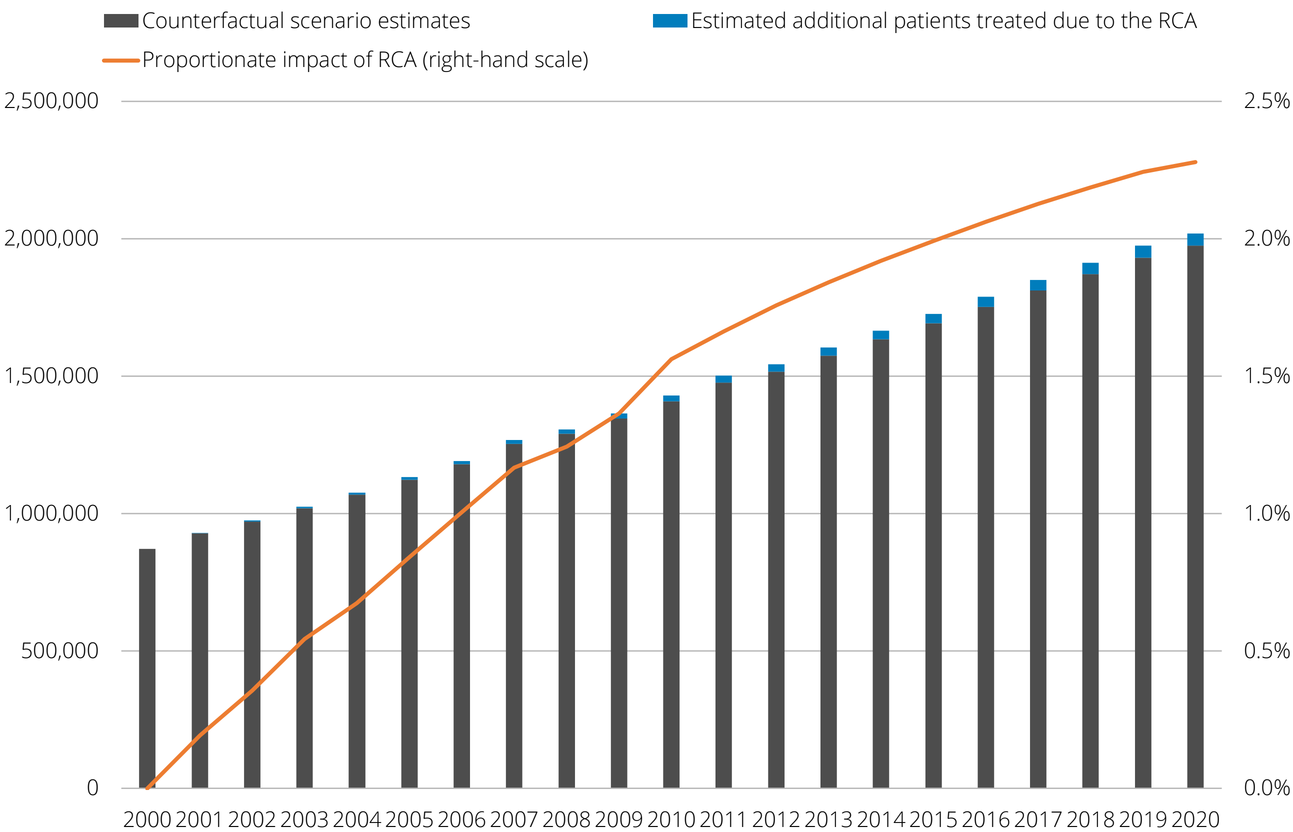


Figure 31: Estimated number of cancer patients treated with radiotherapy in RCA State Parties in the baseline scenario. Source: Calculated.

42 In the sensitivity analysis reported below, we test how the results vary with changes in the assumed impact of the RCA on radiotherapy treatment volumes.

Economic and social benefits of increased use of radiotherapy under the RCA

Benefits in terms of additional health-adjusted life-years were calculated for the estimated additional patients who were treated under the RCA (Figure 31 above). These benefits were calculated by applying the overall five-year survival benefit rates from Table 5 above to the numbers of patients treated, as follows:

- Radiotherapy is usually complementary to other cancer treatments such as surgery and chemotherapy, and the effectiveness of radiotherapy at improving patient outcomes will also depend on the quality of these other treatments. Reflecting this, we applied scaling factors to adjust the five-year overall survival benefits for patients in lower-middle and upper-middle income countries relative to high income countries. In the baseline scenario, we assumed that five-year overall survival benefits of radiotherapy in lower-middle and upper-middle income countries were 60 per cent and 80 per cent respectively of the rates shown in Table 5.
- Patients obtaining a five-year survival benefit from radiotherapy were assumed to receive a benefit of an additional three years of life equivalent to full health (in the baseline scenario). This reflects the fact that not all patients will recover full health within this time and quality of life may be reduced during treatment.
- Of patients who received a five-year survival benefit from radiotherapy, 20 per cent (in the baseline scenario) were assumed to go on to attain a normal life expectancy. The benefits of this in terms of health-adjusted life-years were calculated as the difference between the life expectancy in the relevant State Parties minus the weighted average age of cancer diagnosis.

These assumptions were validated through consultation with IAEA experts. Under these assumptions, Figure 32 shows the number of people that we estimated obtained a survival benefit from additional radiotherapy treatment attributable to the RCA in State Parties, in our baseline scenario.

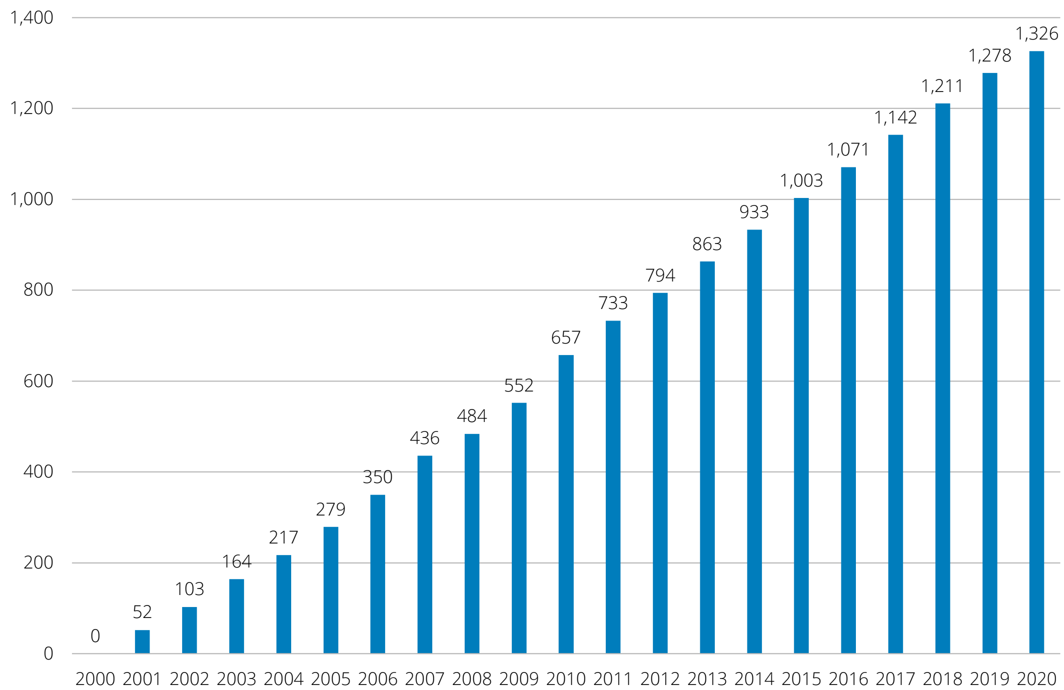


Figure 32: Estimated number of cancer patients in RCA State Parties obtaining a 5-year overall survival benefit from additional radiotherapy treatment under the RCA (baseline scenario). Source: Calculated.

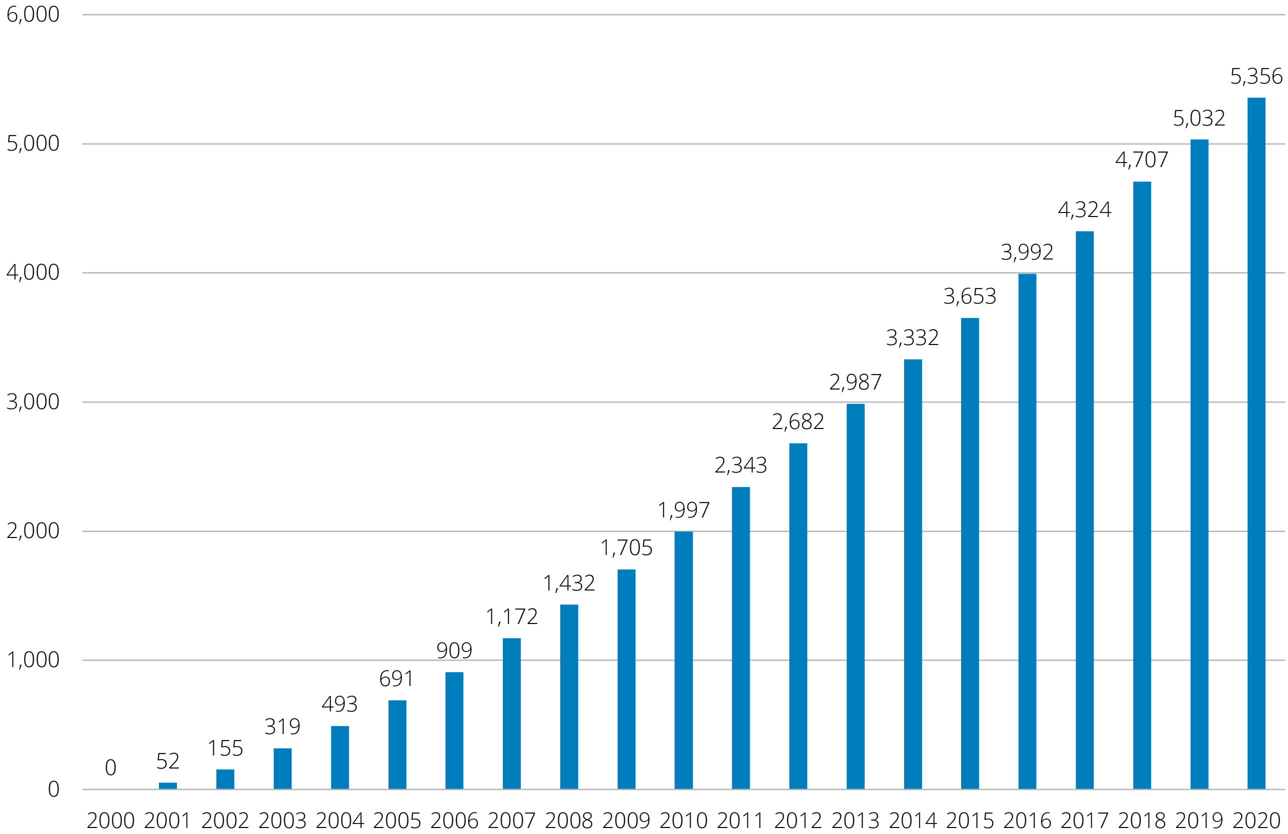


Figure 33: Estimated additional health-adjusted life-years of cancer patients in RCA State Parties from additional radiotherapy treatment under the RCA (baseline scenario). Source: Calculated.

The corresponding additional health-adjusted life-years attributable to the RCA are shown in Figure 33. These were translated into monetary benefits using the three different methods explained above, i.e. using real GDP per capita, or a multiple of real GDP per capita, or a constant value per life year across all RCA State Parties. Additional health-adjusted life-years were also used to estimate the cost-effectiveness of the RCA.[43]

Unquantified benefits of the RCA

Our analysis of the benefits of the RCA is conservative and we have not attempted to quantify the following potential benefits:

- Additional health-adjusted life-years obtained after 2020 by cancer patients treated under the RCA prior to 2020.
- Additional health-adjusted life-years or other benefits due to improved quality of radiotherapy treatment under the RCA (see Figure 26 above).
- Benefits to cancer patients from local control of tumours and/or palliative care that improve quality of life but do not lead to a five-year survival benefit.

Modelling economic costs of RCA activities

The following economic costs attributable to the radiotherapy RCA were modelled:

- Monetary and opportunity costs of RCA State Parties and the IAEA that are directly associated with RCA activities.
- In-kind (non-monetary) contributions of State Parties to support RCA activities.

43 Consistent with standard practice in health evaluations (Drummond, *et al,* 2015), additional health-adjusted life-years attributable to the RCA were 'discounted' in the cost effectiveness calculation using the discount rates described below.

- Operating and capital costs associated with expanded radiotherapy treatment activities (relative to the counterfactual) in State Parties that can be attributed to RCA activities.

Direct costs of RCA activities
Direct costs include costs of radiotherapy RCA activities such as organising and participating in RCA meetings, scientific visits, expert missions, fellowships, and training courses. This includes:

- Costs directly incurred by the IAEA to support these activities.
- Opportunity costs of time for attendees of RCA activities from State Parties.

Annual direct costs incurred by the IAEA from 2000 to 2020 were estimated based on information provided by the IAEA about the type and number of activities under the radiotherapy RCA, and the costs of these activities (Table 7).[44] Including a 10 per cent increment for overhead costs, we estimate that total direct costs incurred by the IAEA for the radiotherapy RCA amounted to around EUR 5.6m from 2000 to 2020, or around EUR 3.8m in discounted present value terms.

Activity	Average cost (EUR)	No. of activities	No. of participants
Training course	52 300	63	1 387
Expert mission	12 892	34	89
Meeting / workshop	23 977	33	519
All other procurement (per year)	14 648	n/a	n/a

Table 7: Estimated direct costs incurred by the IAEA per activity between 2000 and 2020. Source: Calculated from data provided by the IAEA.

Opportunity costs of time for attendees to RCA training courses and meetings or workshops are estimated assuming a 14-day duration for training courses and 7 days for other activities (including travel time). Costs for participants are estimated based on real GDP per capita in each RCA State Party, multiplied by a premium for skilled labour calculated from International Labour Organisation data. In total across State Parties, under our baseline assumptions we estimate the discounted present value of such opportunity costs was around EUR 1.1m from 2000 to 2020.

Costs of in-kind contributions from RCA State Parties
We understand that State Parties contribute to the cost of RCA activities by providing ‘in-kind’ services such as the use of conference facilities, and administrative staff time. The value of these in-kind contributions is estimated based on averages provided by the IAEA:

- Training course hosting: EUR 1 600 per day
- Non-training activity hosting: EUR 800 per day
- Staff cost for training or expert missions: EUR 160 per day

Under these assumptions and based on activity data provided by the IAEA, under our baseline assumptions we estimate the total discounted present value of in-kind contributions of RCA State Partieswas around EUR 1.1m from 2000 to 2020.

Indirect costs of expanded radiotherapy activities in RCA State Parties
As explained above, we estimate that the RCA led to a small proportionate increase in patients treated with radiotherapy in RCA State Parties (Figure 31 above). These additional treatments have costs which are not directly associated with the RCA but can be attributed to it. We modelled additional capital and operating costs

44 Cost information was only available for years from 2011 to 2020. Average costs per activity calculated from these years were applied to activities that took place from 2000 to 2010.

of radiotherapy in State Parties associated with the RCA using the cost estimates in Table 8, obtained from the literature.

Additional operating costs are assumed to be in direct proportion to the number of additional radiotherapy treatment fractions required by the additional patients treated under the RCA. Additional capital costs were modelled if and when additional radiotherapy treatment machines were estimated to be required in RCA State Parties to provide capacity to treat additional patients under the RCA in any given year relative to the counterfactual scenario.

Country income category	Operating costs per fraction	Capital costs per fraction	Capital costs per radiotherapy machine
High income	212	724	6.2m
Upper middle income	78	322	3.4m
Lower middle income	59	315	3.3m

Table 8: Estimated costs of radiotherapy treatment (EUR). Source: Calculated from Atun *et al* (2015, p. 1165).

In our model, the assumed operating cost per radiotherapy treatment session ranges from EUR 59 in lower-middle income countries to EUR 212 in higher income countries (Table 8 above). At a country level, the overall average cost of treating a patient with radiotherapy depends on the mix of types of cancers in that country, as some types need more treatment sessions than others (Table 5 above). The estimated current (2020) operating cost per patient treated with radiotherapy in our model ranges from around EUR 1 100 per patient in lower-middle income countries (e.g. Bangladesh, Indonesia, Philippines) to EUR 4 236 per patient in high income countries (e.g. Japan and Singapore).

The resulting additional operating and capital costs incurred in RCA State Parties due to additional radiotherapy treatment volumes under the RCA are shown in Figure 34 for the baseline scenario. Under baseline assumptions, we estimate costs of EUR 684m across State Parties in present value terms between 2000 and 2020. These costs are associated with treatment of around an additional 460 000 cancer patients

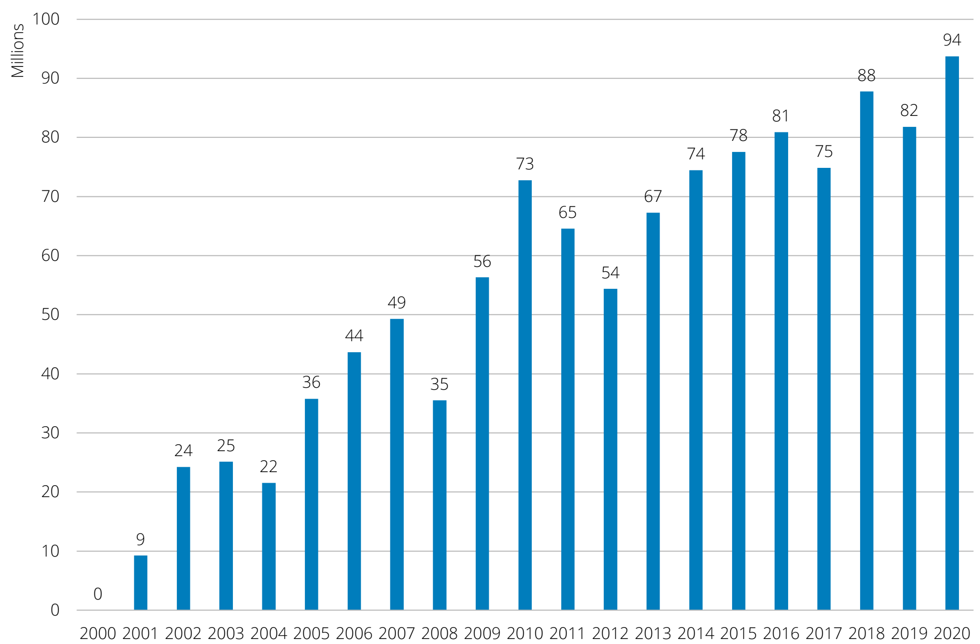


Figure 34: Modelled additional operating and capital costs associated with increased radiotherapy treatment volumes under the RCA (EUR, baseline scenario). Source: Calculated.

treated under the RCA compared to the counterfactual (the sum of the blue bars in Figure 31). Thus the additional costs attributable to the RCA average approximately EUR 1 500 per additional patient treated. The majority of these costs are operating costs of additional radiotherapy treatments provided, which are on average around EUR 1 000 per patient treated across all years.

Outputs of the economic model

Benefit-cost ratios

The socio-economic model produces three average benefit-cost ratio (BCR) across all RCA State Parties from 2000 to 2020 under the three different assumptions described above. These BCRs reflect the average benefits attributable to the RCA for each one euro of costs that are directly and indirectly attributable to the RCA. Each BCR is calculated as the ratio of the present value of economic benefits attributable to the RCA to the present value of economic costs attributable to the RCA, across all State Parties. A BCR greater than one indicates that estimated benefits of the RCA exceed its estimated costs.

We focus on these average BCRs rather than the absolute value of estimated net economic benefits (i.e. benefits minus costs) to evaluate the performance of the RCA against the economic rubrics that were defined for this evaluation (Annex G) while recognising that the estimated economic benefits are likely understated.

It is important to note that the estimated BCRs are average effects across RCA State Parties for the historic RCA activities from 2000 to 2020. We have not estimated the potential impacts of expanding or reducing the scale of RCA activities, and the estimated BCRs should not be used to guide future decisions about RCA activities. Instead, the estimated BCRs reflect average economic performance of the actual RCA activities between 2000 and 2020.

Cost effectiveness

The estimated cost effectiveness ratio (CER) of the RCA tells us the average cost of each additional life-year attributable to the RCA. This estimate can be compared to either estimated willingness to pay for health-adjusted life-years, or to benchmark CERs for other treatments (or both). As noted above, from the literature we have estimated an average willingness to pay for an additional life year across RCA State Parties of EUR 27 000. This provides one benchmark against which the CER of the RCA can be compared. In addition, we have identified the following benchmarks for other types of cancer treatment:

- A systematic review of cost-effectiveness ratios for cancer treatments in the United States (Greenberg *et al,* 2010) found median cost-effectiveness ratios of US$27 000 (EUR 23 000) for breast cancer, US$22 000 (EUR 19 000) for colorectal cancer, US$34 500 (EUR 29 500) for prostate cancer and US$32 000 for lung cancer (EUR 27 400).
- Kang *et al* (2016) reference a threshold of GBP 20 000–30 000 (EUR 23 300–35 000) for cancer treatments that are considered cost-effective in the UK and US$100 000 (EUR 85 500) in the United States.
- Konski (2018) reviewed studies of the cost-effectiveness of radiotherapy for prostate cancer treatment and found cost-effectiveness ratios of below US$50 000 (EUR 43 000) for most types of treatment.

Discounting and the discount rate

Our socio-economic evaluation is retrospective and estimates benefits and costs that have already occurred. The usual practice in a forward-looking social cost-benefit analysis is to discount future outcomes by a multiple that depends on a social discount rate and how far into the future these outcomes occur.[45] In forward-looking social cost-benefit analysis,

45 Specifically, the discounted value of a benefit or a cost x that occurs t years in the future given a social discount rate of r is x / (1 + r)t.

the justification for such discounting is that there is uncertainty about whether future outcomes will occur, which means benefits and costs that occur now have greater value than those that occur in the future.

In a retrospective cost-benefit analysis there is no uncertainty about whether outcomes will occur. However, to be consistent with the justification for discounting in a social cost-benefit analysis, it is necessary to carry out a retrospective analysis *as if* it were a forward-looking analysis and to discount benefits and costs over time in the same way. In addition, capital invested in radiotherapy activities in State Parties due to the RCA could have been put to alternative uses and this generates opportunity costs. For these reasons, our analysis discounts all benefits and costs incurred between 2000 and 2020 back to the year 2000. For ease of interpretation, we express all benefits and costs in real (inflation-adjusted) 2020 euros.

The discount rates used in our analysis are derived from estimates provided by Haacker *et al* (2020), who argued that higher discount rates are appropriate in lower middle and upper middle income countries that are experiencing higher rates of economic growth compared to high income countries. We used the discount rates calculated by Haacker *et al* shown in Table 9 and calculated a weighted average across RCA State Parties based on population. This gives a weighted average discount rate of 4.2 per cent. We also tested alternative discount rates of 2.2 per cent and 6.2 per cent as part of our sensitivity analysis.

Income category	Discount rate (%)	2020 population in RCA State Parties (millions)
High income	2.0	214
Upper middle income	3.5	1 542
Lower middle income	4.8	2 378

Table 9: Discount rates by income category. Source: Discount rates are from Haacker et al (2020, table 2, unweighted averages for 2007 to 2017). Population figures are from the United Nations.

Summary of key assumptions and sensitivity testing

Table 10 summarises the key parameters of the economic model, including baseline values and low and high alternatives used for sensitivity testing. Two types of sensitivity testing were performed:

1. Setting each parameter at its alternative low and high values while maintaining all other parameters at their baseline values. This helps to reveal the sensitivity of the results to changes in each individual parameter.
2. Generating results across all combinations of the three alternative values for each of the parameters in Table 10 (a total of 177 147 combinations).[46] This gives the potential overall range of results assuming it is equally likely that each parameter could take its low, baseline or high value.

46 To maintain a manageable number of scenario combinations we linked the two parameters for the relative effectiveness of radiotherapy in lower middle and upper middle income countries, so that both of these parameters take their low, baseline, or high values at the same time.

Parameter	Low scenario	Baseline value	High scenario
Discount rate (real)	2.2%	4.2%	6.2%
Overhead costs of RCA activities as a proportion of direct costs	5.0%	10.0%	20.0%
Radiotherapy RCA workshop duration (days incl travel time)	5	7	9
Radiotherapy RCA expert mission duration (days incl travel time)	5	7	9
Radiotherapy RCA training course duration (days incl travel time)	12	14	16
Additional health-adjusted life-years benefit from 5-year survival	2	3	4
Proportion of cancer patients treated with radiotherapy and surviving for 5 years who attain average life expectancy	10%	20%	30%
Relative 5-year survival benefit of radiotherapy in upper-middle income countries	60%	80%	100%
Relative 5-year survival benefit of radiotherapy in lower-middle income countries	40%	60%	80%
GDP multiple for local social benefits approach	1.9	2.4	2.9
Value of life-year under international social benefits approach	EUR 20 000	EUR 2 000	EUR 34 000
Increase in radiotherapy treatment volumes attributable to the RCA*	2.0%	3.1%	4.4%

Table 10: Summary of parameters of the socio-economic model.

Baseline and scenario values shown are averages across RCA State Parties. The model uses different values for these parameters for each State Party, based on survey responses.

Results from the economic analysis

Baseline results

Table 11 summarises the results produced by the socio-economic model under the baseline assumptions in Table 10 above. Each additional health-adjusted life-year attributable to the RCA costs around EUR 26 000 on average. This estimate reflects the combination of:

- Estimated costs of RCA activities incurred by the IAEA and by RCA State Parties
- Estimated operating and capital costs of additional radiotherapy treatments provided in RCA State Parties that are attributable to the RCA.
- The number of additional radiotherapy treatments estimated to be attributable to the RCA, and the effectiveness of radiotherapy at extending the lives of cancer patients treated.

If health-adjusted life-years are valued only at real GDP per capita in RCA State Parties ('pure economic benefits') then the value of benefits generated is slightly more than half of the costs attributable to the RCA. However once broader social benefits associated with additional life-years are accounted for then the value of the benefits exceeds the value of costs in the baseline scenario ('local social benefits' or 'international social benefits'). The greatest BCR is found under the 'local social benefits' approach which values additional health-adjusted life years at 2.4 times real GDP per capita, as explained above.

Method	Baseline result
Cost-effectiveness: EUR per life-year	26 019
BCR: Pure economic benefits	0.55
BCR: Local social benefits	1.31
BCR: International social benefits	1.04

Table 11: Summary of cost-effectiveness and cost-benefit results in the baseline scenario from 2000 to 2020.

It should be noted that we have assumed that the potential benefits of radiotherapy are constrained by the quantity and quality of complementary medical care in lower middle and upper middle income State Parties, as discussed above. If not for these constraints, the estimated BCRs of the RCA between 2000 and 2020 would have been 0.71, 1.72, and 1.56 under the pure economic benefits, local social benefits, and international social benefits methods respectively.

These results show that the cost-effectiveness of additional treatments enabled through the activities of the RCA was comparable to other cancer treatments, based on the benchmarks cited above.

Sensitivity testing

Figures 35 to 38 on the following pages show the results of sensitivity testing by changing one parameter at a time on the estimated cost effectiveness and BCRs for the RCA.[47] In all cases, the results are most affected by the assumed relative effectiveness of radiotherapy treatment in lower middle and upper middle income countries (i.e. constraints on other parts of the cancer treatment system such as chemotherapy and surgery, which are outside the remit of the RCA) and the parameters reflecting five-year survival benefits. The results under the 'local social benefits' method also depend on the GDP multiplier assumption used to capture social benefits, and the results under the 'international social benefits' method depend on the assumed constant value of health-adjusted life-years. The results are relatively insensitive to changes in parameters specific to the RCA, including the assumed impact of the RCA on cancer treatments, course and workshop durations and the discount rate.

47 Not all parameters are relevant for all results. For example, the value of a life-year is only applicable to the BCR under the 'international social benefits' method.

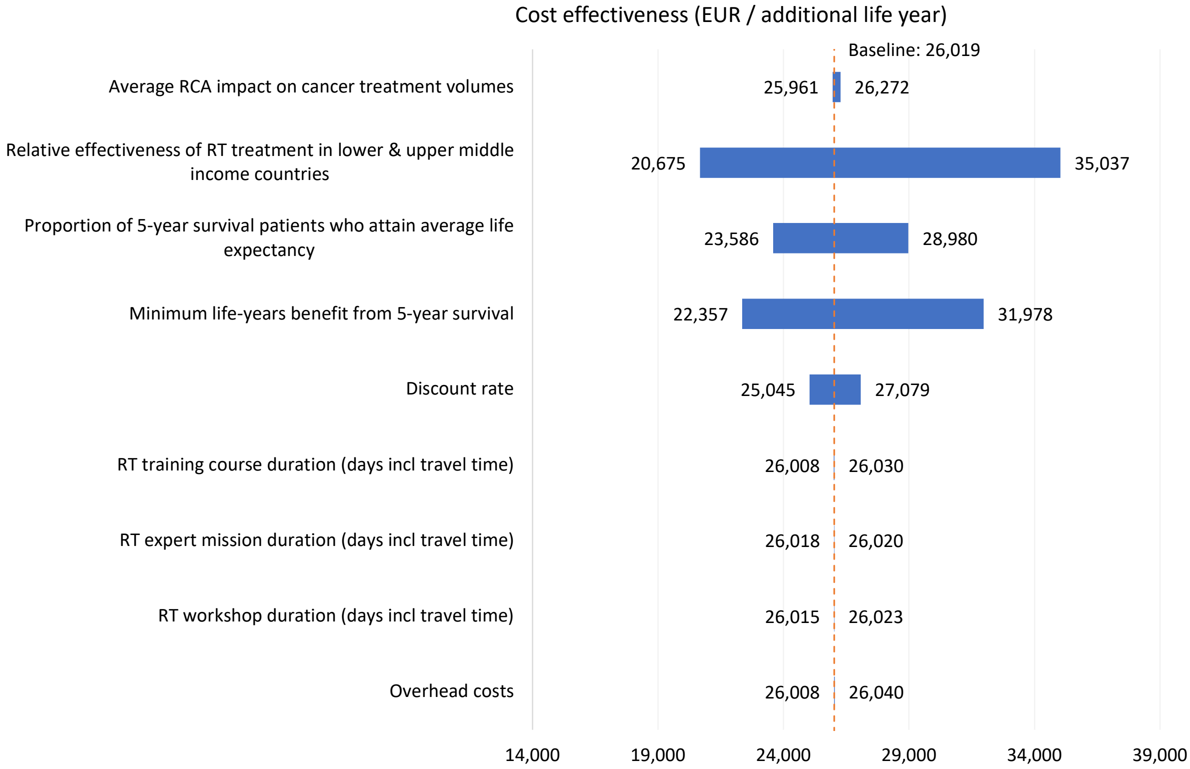


Figure 35: Sensitivity of estimated cost-effectiveness to changes in individual model parameters.

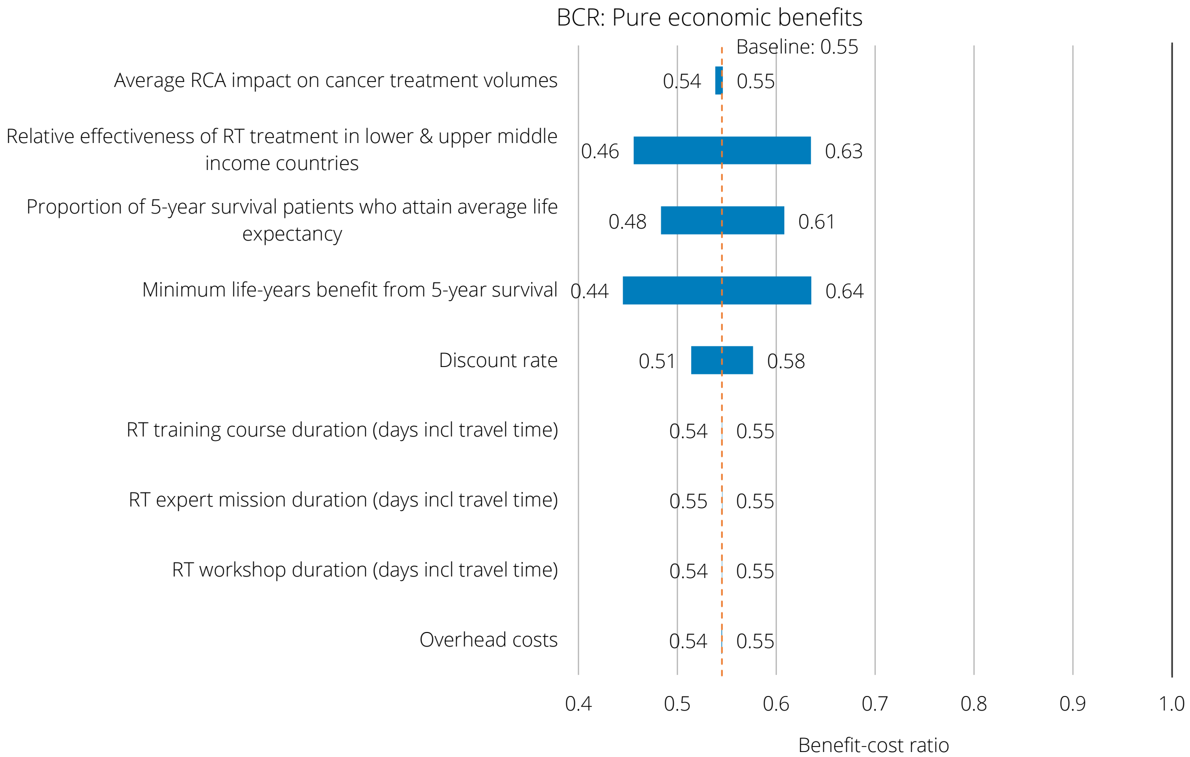


Figure 36: Sensitivity of estimated BCR of pure economic benefits to changes in individual model parameters.

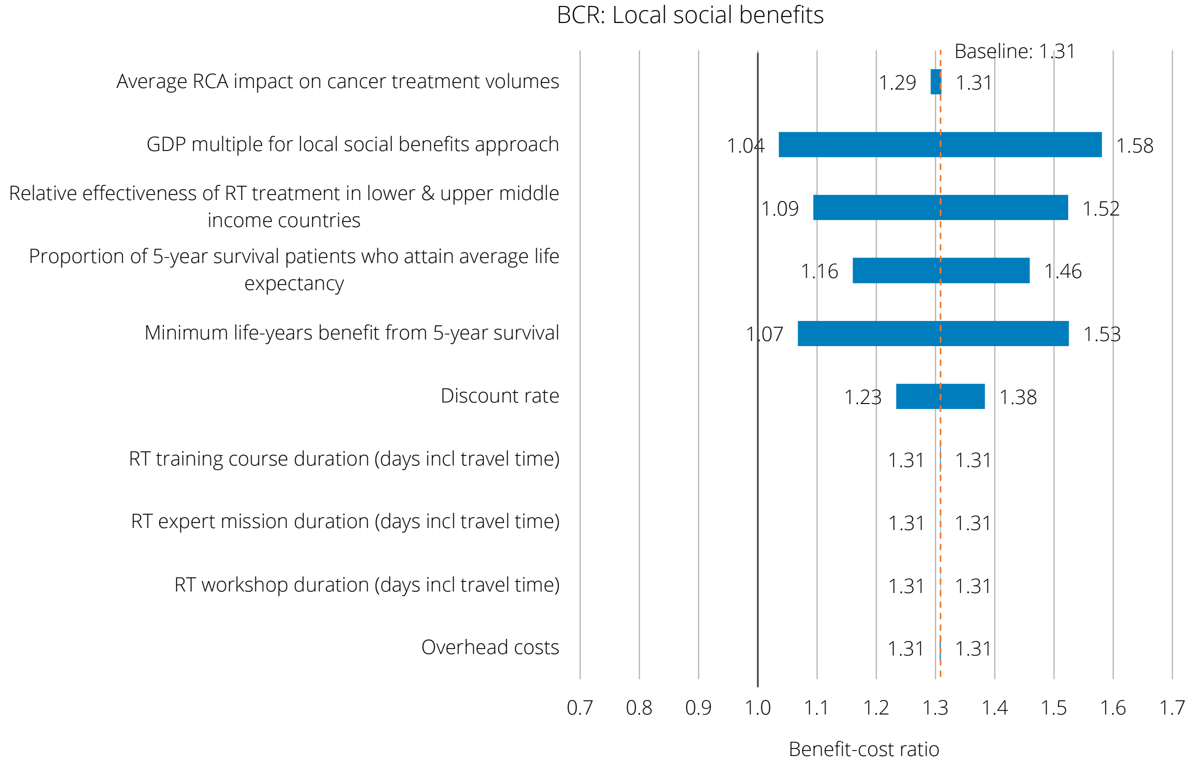


Figure 37: Sensitivity of estimated BCR of local social benefits to changes in individual model parameters.

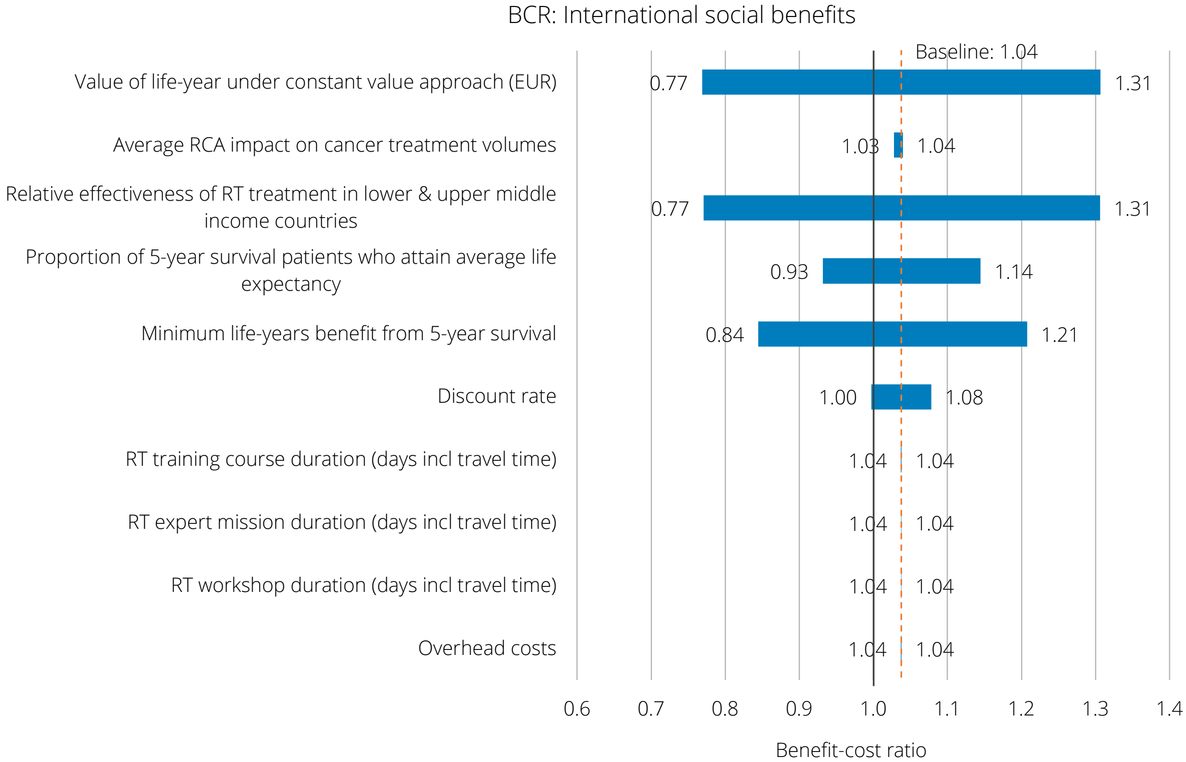


Figure 38: Sensitivity of estimated BCR of international social benefits to changes in individual model parameters.

Figure 39 shows the results of sensitivity testing involving all possible combinations of the parameters in Table 10 above. The median BCR and the range within which 95 per cent of results of these simulations lie are shown for each of the three BCR methods. Across all scenarios tested, the 'international social benefits' BCR is greater than one in 48 per cent of scenarios, and the 'local social benefits' BCR is greater than one in 77 per cent of scenarios. The 'pure economic benefits' BCR was always less than one in all scenarios. In addition, the median cost-effectiveness was EUR 27 260 per life-year, with 95 per cent of results falling between EUR 17 045 and EUR 49 957 and half of results falling between EUR 22 000 and EUR 33 196 per life year.

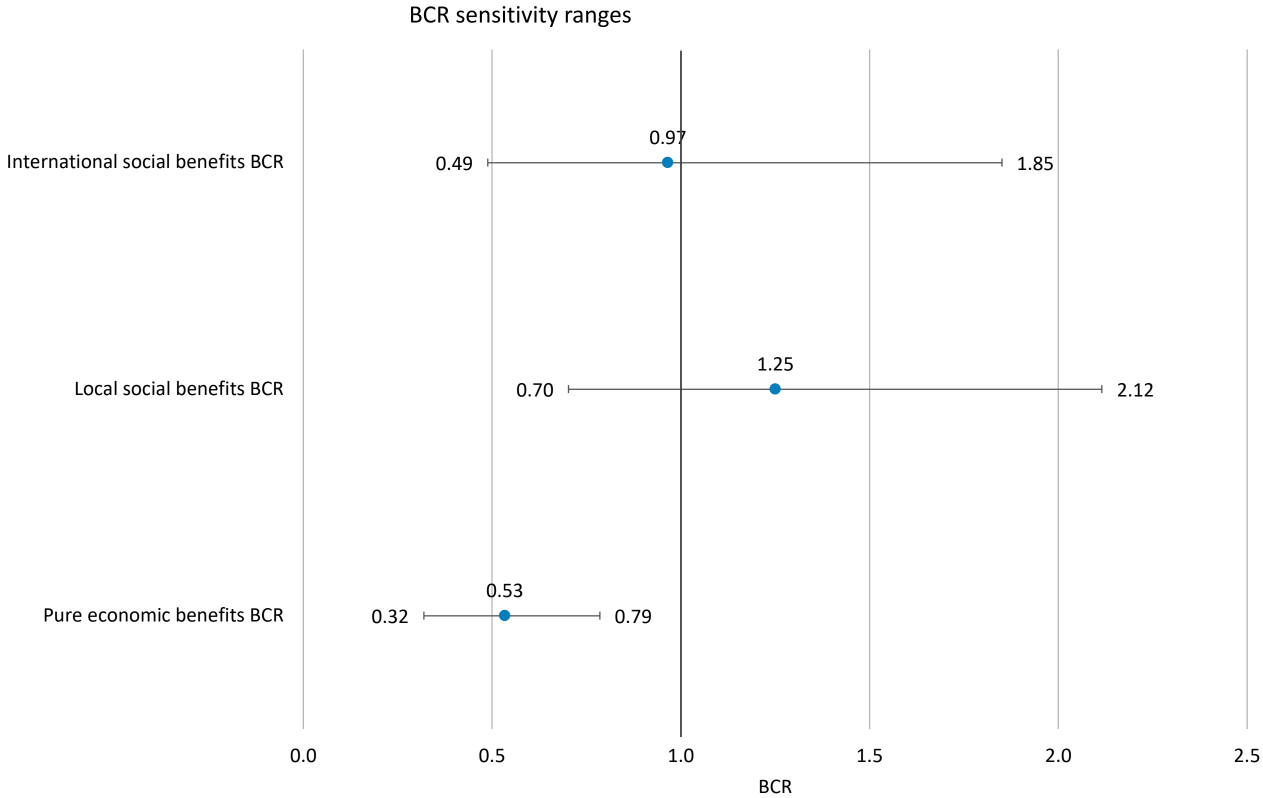


Figure 39: Median and ranges within which 95 per cent of estimated BCRs lie when testing all combinations of parameters.

Discussion

This analysis investigated the potential economic benefits and costs of enhanced radiotherapy that can be attributed to the RCA. It is best understood as a break-even analysis, because it is assessing whether enough benefits can be identified to exceed costs, bearing in mind data limitations that prevented some benefits being quantified.

Our analysis of the benefits of the RCA is conservative because it does not include additional health-adjusted life-years gained after 2020 and attributable to the investment up to 2020, benefits from improved quality of radiotherapy treatment facilitated through the RCA, or benefits to cancer patients from local control of tumours and/or palliative care.

Under these conservative parameters, the RCA investment in radiotherapy more likely than not breaks even – that is, under baseline assumptions, and under more than half of the scenarios modelled, the investment created more value than it consumed. Furthermore, the gain in health-adjusted life-years attributable to the RCA is within range of our estimated willingness-to-pay threshold.

Additionally, it should be noted that the modelled results reflect assumptions that the potential benefits of radiotherapy are constrained by the quantity and quality of complementary medical care, such as chemotherapy and surgery, in lower-middle and upper-middle income RCA State Parties. The value of the RCA's contribution to health system *potential* may be greater than our estimates of the realised value, because of these constraints.

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Annex G: Methodology

The social and economic impact assessment methodology was developed specifically for IAEA, for case studies of Technical Cooperation (TC) projects under the Regional Cooperative Agreementfor 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 (King, 2017; King, 2019; King & OPM, 2018) and the Kinnect Group approach to evaluation rubrics (King *et al.,* 2013; McKegg *et al.,* 2018).

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.

Developing the methodology

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 TCAP, TCPC, and invited experts from China and New Zealand. Invited experts Dr Julian King and Kate McKegg summarised and compared approaches and tools for social and economic impact assessment. A methodology was proposed – *Value for Investment* – that combines strengths from the disciplines of economics and evaluation.

Evaluation is the systematic determination of the merit, worth or significance of something.

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 realisation 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), recognising that one outcome can arise from many contributions (of which the RCA project may be only one) and conversely one project may contribute to many different outcomes or impacts.

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 (King, 2019). Economics and evaluation bring different approaches to valuing. For example, cost-benefit analysis uses money as the metric for understanding value (Drummond *et al.,* 2005), while other approaches include numerical or qualitative synthesis (Davidson, 2005), or citizen deliberation (Schwandt, 2015).

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 programme or project, including its context, stakeholders and theory of change.
2. Develop performance criteria – the aspects of social and economic impacts that will be the focus of the evaluation – e.g., strengthened radiotherapy workforce, increased access to quality radiotherapy, etc.
3. Develop performance standards for each criterion – narratives that describe levels of performance such as ‘excellent’, ‘good’, ‘adequate’ and ‘inadequate’.
4. From the criteria and standards, select and identify the evidence needed and the methods that should be used to gather the evidence – e.g., surveys, case examples, administrative data, etc.
5. Gather evidence. Note that the evidence needed and means of gathering it need to be tailored to the circumstances of the project.
6. Analyse the evidence. At this stage, each evidence source is analysed separately, using methods suited to each source – e.g., quantitative analysis of survey data, qualitative analysis of case examples, economic analysis of costs and benefits.
7. Synthesise the evidence. At this stage, the streams of analysis are brought together to make evaluative judgements – ratings of performance according to the agreed criteria and standards.
8. Reporting, based on the criteria agreed in advance.

Following this sequence of steps helps ensure the evaluation is aligned with the RCA context, gathers and analyses the right evidence, interprets the evidence on an agreed basis, and provides clear conclusions about the RCA’s social and economic impact. Involving stakeholders in the design of the evaluation and the interpretation of findings supports understanding, ownership, validity and use (King, 2019).

The methodology was piloted in a case study of mutation breeding projects under the RCA (King, McKegg, Arau, Schiff, & Garcia Aisa, 2020) before being deployed in subsequent case studies.

Applying the methodology

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 (King, 2019). A theory of change “explains how activities are understood to produce a series of results that contribute to achieving the final intended impacts” (Rogers, 2014, p. 1).

The theory of change for the radiotherapy programme (Figure 40) was developed iteratively by IAEA, selected experts from participating State Parties, 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 (Funnell & Rogers, 2011).

A theory of change may be used as a tool when assessing causality or contribution (Funnell & Rogers, 2011). In the case of radiotherapy 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 theorised that regional collaboration would add value by strengthening the radiation oncology workforce, supporting the establishment of professional networks and societies, and increasing patient access to quality radiotherapy. It was further theorised that these impacts would contribute to increasing lifespan and quality of life, and associated economic benefits. These theories were tested by eliciting feedback from the participating countries.

A theory of change can also be used to help identify a complete and coherent set of evaluation criteria (Davidson, 2005). For the radiotherapy case study, it was agreed that the focus of the evaluation would be on four impact areas:

- Strengthened radiotherapy workforce (including educational training programmes, establishment of radiation oncology departments and societies, and developing specialists in the area of radiation oncology)
- Increased access to quality radiotherapy (including increased adoption of operational radiotherapy equipment and technology, improvements in treatment quality, and increased numbers of patients using domestic radiotherapy facilities)
- Increased life span and quality of life (including increases in 5-year tumour control rates and 5-year survival rates)
- Economic benefits associated with collaboration under the RCA.

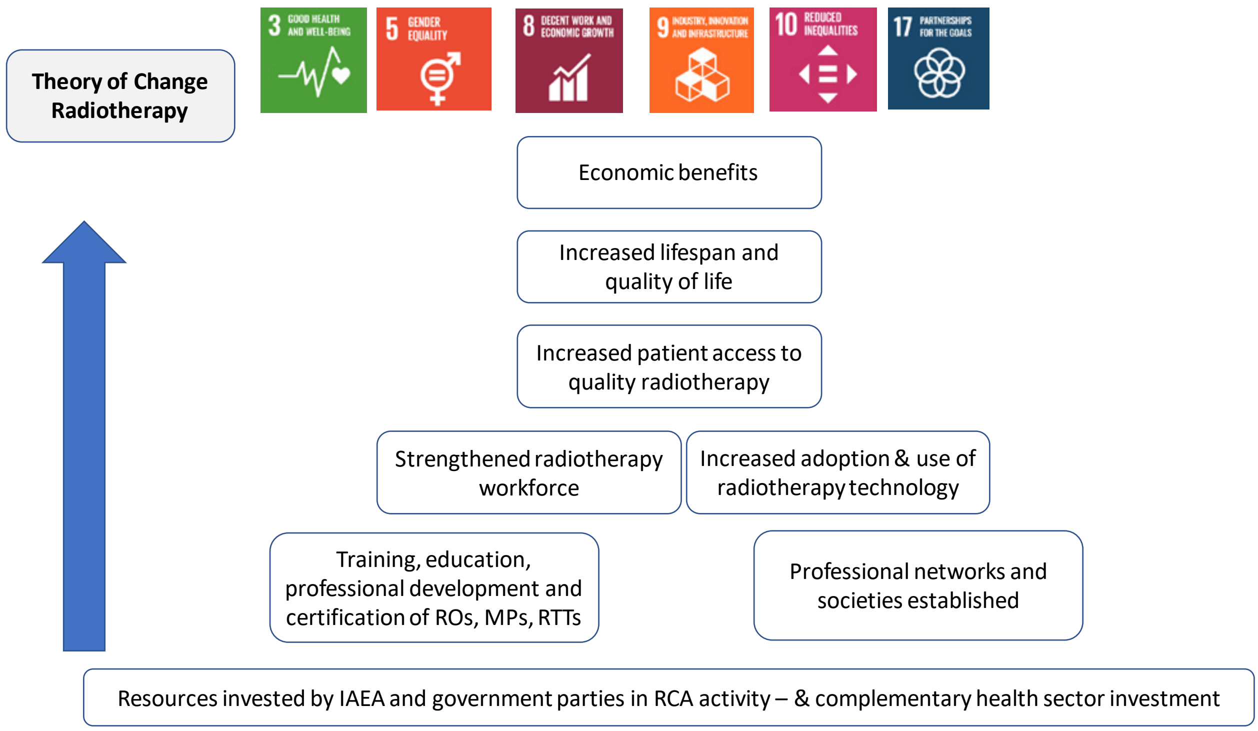

Figure 40: Theory of change for RCA radiotherapy projects

Criteria and standards

Evaluation criteria and standards for the four impact areas were collaboratively developed. Tables 12–14 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.

Standard (to be applied to each State Party)	Criterion 1: Strengthened radiotherapy workforce
Excellent (exceeding expectations) Meets the standard for Good, plus:	Significant increase in: • Educational programmes; • Radiation oncology departments; • National societies/ regional radiation oncology societies; *and* • ROs/MPs/RTTs (certified and uncertified)
Good (meeting expectations) Meets the standard for Adequate, plus:	Some increase in: • Educational programnes; • Radiation oncology departments; • National societies; *and* • ROs/MPs/RTTs (certified and uncertified)
Adequate (meeting bottom-line expectations)	Any increase in: • Educational programmes; • Radiation oncology departments; • National societies; *and* • ROs/MPs/RTTs (certified and uncertified)
Inadequate	No material increase in educational programmes, radiation oncology departments, national societies, or ROs/MPs/RTTs

Table 12: Rubric for criterion 1: strengthened radiotherapy workforce

Standard (to be applied to each State Party)	Criterion 2: Increased access to quality radiotherapy
Excellent (exceeding expectations) Meets the standard for Good, plus:	Significant increase in: • Population coverage of radiotherapy machines • Technologies introduced by the RCA projects including 3D-CRT, IMRT, particle therapy, SRT, 3D-IGBT • Waiting times from admission to treatment < 5 days *and* • Patients receiving radiotherapy. There is a significant upgrade of quality relevant to the radiotherapy technique/ service of the RCA in the participating countries.
Good (meeting expectations) Meets the standard for Adequate, plus:	Some increase in: • Treatment machines • New technologies introduced by the RCA projects; • Waiting times from admission to treatment < 7 days *and* • Patients receiving radiotherapy. There is some upgrade of quality relevant to the radiotherapy technique/ service of the RCA in the participating countries, though the increase is not remarkable in percentage terms.
Adequate (meeting bottom-line expectations)	Any increase in: • Treatment machines • New technologies introduced by the RCA projects; • Patients receiving radiotherapy; • Waiting times from admission to treatment < 10 days *and* • Quality improvement.
Inadequate	No increase in treatment machines, new technologies introduced by RCA projects, patients receiving radiotherapy, and quality improvement.

Table 13: Rubric for criterion 2: increased access to quality radiotherapy

Standard (to be applied to each State Party)	Criterion 3: Increased life span and quality of life
Excellent (exceeding expectations) Meets the standard for Good, plus:	Significant increase in local control data or survival data, with low incidence of complications. Significant increase in life-years. High satisfaction reported in radiotherapy centres by applying the relevant method/ technologies.
Good (meeting expectations) Meets the standard for Adequate, plus:	Some increase in local control data or survival data, with low incidence of complications. Some increase in life-years. Patients were reported somewhat satisfied.
Adequate (meeting bottom-line expectations)	Any increase in local control data or survival data, with low incidence of complications. Any increase in life-years. Neutral patient satisfaction.
Inadequate	Any of the standards for Adequate not met.

Table 14: Rubric for criterion 3: increased life span and quality of life

Standard (to be applied to each State Party)	Criterion 4: Economic benefits
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).
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)
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)
Inadequate	Break-even is unlikely (or only possible under optimistic assumptions)

Table 15: Rubric for criterion 4: economic benefits

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, the 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 (King & OPM, 2018).

Examination of the rubric 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. 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 radiotherapy project activity and costs, provided by IAEA
- Gathering additional information from radiotherapy experts at the IAEA and State Parties
- Narrative case examples, written from details provided by selected countries
- Economic analysis of costs and benefits associated with collaboration under the RCA.

Online questionnaire

The online questionnaire was designed and piloted in May 2021 and deployed between June and August 2021. The data collection period coincided with the onset of the COVID-19 pandemic. The support and cooperation of country representatives and IAEA staff during these unusual circumstances is gratefully acknowledged.

The survey was structured in alignment with the rubrics, to capture evidence needed in the four 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 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 where needed to clarify responses, and thanking country representatives for their close and effective cooperation). This communication and coordination from IAEA was critical to the success of the survey.

Case examples

Development of the case examples occurred following survey data collection. The selection of case examples was agreed with 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 study data, follow up contact was made with the contact people as required to clarify details. Narrative summaries were prepared.

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