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Key messages

Our brief

The need to ensure efficient use of radiotherapy infrastructure is well recognised by NSW Health. In 2006/07, in conjunction with the Cancer Institute NSW (CI NSW), a Business Process Improvement (BPI) project was undertaken for radiotherapy services in NSW. This was completed in 2009. The BPI project has demonstrated that improvements in efficiencies can be realised with existing infrastructure with the improvements in operational processes.

In 2009, the NSW Audit Office conducted a Performance Audit of NSW radiotherapy services and recommended that NSW Health, 'assesses economies of scale to assist in considering the most cost effective linear accelerator machine configuration and the impact on access to services'. The NSW Department of Health therefore commissioned the Centre for Health Service Development (CHSD) to undertake a targeted literature review to continue to assist NSW Health in responding to this issue.

Radiotherapy

Radiation treatment is one of the fundamental tools available in cancer treatment and one of the three cornerstones of multidisciplinary cancer care, along with chemotherapy and surgery as part of a quality comprehensive cancer service. Radiotherapy can be given in two ways, through external beam radiotherapy (which uses high energy machines) and brachytherapy (which uses radioisotopes). "Megavoltage" treatments are an external beam radiotherapy delivered by linear accelerators. These machines are often referred to as linacs.

Search strategy and literature

Our approach is based on purposive literature review techniques aimed at finding key articles/documents from the academic and practice literature (both national and international). The US National Library of Medicine's MeSH terminology was used to generate search terms which were then used in various combinations. Initially the results from our primary search were not that promising and unsurprisingly the search term 'machine configuration' generated virtually nothing. We then widened our search terms with the most useful search terms in various combinations including: radiotherapy, radiation therapy, utilisation and efficiency.

There is limited academic literature relating to optimal machine configurations for radiotherapy services. Our expanded search strategy found the most useful literature focused on related aspects of utilisation. We were particularly looking for references to economies of scale.

A search of the practice literature relating to radiotherapy identified Australia and the United Kingdom as most prolific in developing and publishing reports and material related to radiotherapy infrastructure and services planning. Useful practice literature was also sourced from Canada and the United States and Europe.

Exclusions

Whilst there are diverse issues that impact upon radiotherapy services planning, many are outside the scope of this literature review. We have deliberately not addressed in detail the various models used to estimate the number of linear accelerators required for given populations and treatment rates.

Findings and evidence

The evidence from this targeted literature review is equivocal; the optimal size of a radiotherapy service has not been identified in the Australian context. Planning to achieve economies of scale

through the most cost effective machine configuration needs to be considered in light of not only the impact on access to services but also issues such as costs, machine capacity, workload and throughput considerations, workforce availability, quality and safety. In our view, it is this combination of factors that can best inform thinking about optimal machine configuration.

Multiple factors will influence decision-making for this service planning issue. This literature review provides another ingredient for the 'melting pot', it will be supplemented by new and emerging evidence, advances in best practice, the advice of clinical and technical experts, patient preferences and undoubtedly available public funds.

In summary the major findings from the literature are:

Costs and Economics

- Radiotherapy capacity to respond to increasing cancer numbers requires long term planning and investment in education and infrastructure.^{10, 56, 80}
- Radiotherapy requires a large 'up-front' capital investment with these costs amortised over the ten to twelve-year machine life.^{9, 46, 51, 57, 59}
- Radiotherapy is a cost-effective treatment option.^{23, 57}
- Radiotherapy continues to evolve with new technology and techniques widening the indications and options for therapeutic treatment and palliative care.^{10, 57, 75}
- Smaller facilities are seen to have an impact on the cost and cost-effectiveness of radiotherapy services.^{9, 29, 79}
- A simulation study from Ontario, Canada concluded that the cost of radiotherapy in a facility treating less than 1600 patients per year starts to rise. At 400 patients per year, a course costs approximately 50% more than at 1600 patients per annum. The significant increase in cost below 1600 patients per year comes from underutilisation of ancillary equipment. The slow decrease in cost above 1600 patients results from the sharing of the cost of supervisory positions over a greater number of patients. On the basis of this model the authors found no significant economies of scale for facilities with more than four fully utilised treatment units.²⁹
- The Evaluation of the National Single Machine Unit (SMU) Radiotherapy Trial conducted in Victoria commenced in 2003 included information on the costs and economics of SMUs. The additional costs of providing treatment at the SMUs compared to the hubs ranged from \$0.2 to \$1.3 million per annum. This reported wide variation is derived from a small sample size.⁷⁹
- Costs per course at the regional centre of Ballarat were between 19-36 per cent higher than the metropolitan hub, at the Austin. The higher uptake of IMRT at this centre may have been a factor. Activity levels at all centres most significantly impacted on cost per course.⁷⁹
- A comparative analysis of a Commonwealth-initiative regional radiation oncology facility in Toowoomba with a Queensland health facility found that the average Medicare cost per treatment course was similar in both centres (\$5000 per course). Total costs of an average treatment including patient, State and Commonwealth costs, showed a 30% difference in costing favouring Toowoomba. Most of this difference is reflected in the staffing levels.⁶¹
- The cost of radiotherapy is mainly determined by the length of the treatment (number of fractions) and by the daily treatment time. This means that departments should be of sufficient size to optimise cost-effectiveness.¹⁰
- Even in this era of very sophisticated and costly radiotherapy equipment, personnel costs remain the most important cost component of a radiotherapy department, consuming about twice the budget of equipment (in the magnitude of 52% versus 28%).^{10, 53}
- Costing models should be developed at a supra-institutional, international level. Such a costing model would yield the necessary cost data to perform economic evaluations of new treatment strategies and potentially analyses relating to scale.^{10, 41}

- Planning and service development strategies should not focus only on economies of scale, there are references in the literature to 'economies of scope' which can be realised because of the complementarity of radiotherapy as a treatment modality with other treatment modalities, this in turn generates a demand for a certain level of hospital infrastructure.^{60, 70}

Machine Capacity

- Planning parameters, such as population catchments, cancer incidence, evidence based treatment guidelines and machine throughput are considered when determining linear accelerator requirements.^{9, 70, 80}
- The utilisation of equipment offers potential to achieve economies of scale.^{29, 53, 60}
- Linear accelerator throughput is quantified as the number of treatment courses per year. This will vary with a multitude of factors including the complexity of delivered treatments, number of fields, number of dose fractions, extent of quality assurance procedures and the efficiency of equipment and staff, including processes, workflow and technological developments.^{9, 10}
- Several studies have shown that maximum acceptable percentage utilisations are between 85-95% depending on the number of matched linacs and on the maximum acceptable delay.⁷⁴
- Linear accelerators cannot be run at average utilisations in excess of 90% without causing delays to patients' treatments as a result of random fluctuations in demand.⁷⁴ This only in a no waiting list scenario. Where a waiting list exists, this does not apply.
- The level of excess capacity required to avoid delays depends on whether the machine is run as a single machine or part of a matched pair, additional considerations include the ability to move patients between machines.⁷⁴
- Modelling completed in the UK demonstrates that for a given level of demand, capacity needs to be about 10% greater to avoid queues, (a key assumption being that 86% of patients are able to start radiotherapy within a week of completing the treatment planning process).^{18, 74}
- Studies have shown a high correlation between equipment capacity and degree of utilisation. A high correlation was also found between input of manpower and output of fractions in Swedish departments of radiotherapy.⁵³ This was also achieved through the Victorian SMU trial where utilisation/machine was the highest in the country for Ballarat & Bendigo.^{14, 69, 79}
- Newer machines with more recent technological enhancements have been shown to generate higher throughput.²²
- Satellite centres may start as a single machine unit (SMU) but should be developed with two bunkers to facilitate expansion to a two machine unit.^{9, 15, 27, 31, 47, 61, 62, 79}
- Internationally it is more common for new linacs to be located within existing hub and spoke centres.^{11, 12}
- There are very few examples in the literature of single machine units; the most common number of linear accelerators in a comprehensive cancer centre is customarily between two and four linacs.^{9, 30, 40, 52, 56, 62, 67}
- There is one Belgian study in the literature that reports that a lower threshold for department size was found to be around 1000 patients treated annually, this is primarily because of the impact of economies of scale in the calculation of average and specific radiotherapy costs. Due to the indivisibility of some resources, large-scale departments can treat their patients at a lower cost per case: if a simulator, for example, can serve up to three linacs, then the unit cost for the simulator declines as the volume increases.^{10, 41}
- There is no definitive evidence in the academic literature, relating to the maximum number of linacs within one treatment centre. The maximum number of linacs found in the academic literature was eight in a major Swedish treatment centre but this data was from 2000. A review of the web identified 11 linacs at The Beatson West of Scotland Cancer Centre in Glasgow. The largest number of linacs found in one centre was at the Odette Cancer Centre (13 linacs) and the Princess Margaret Hospital (17 linacs) both within the Toronto Central Region of Canada.^{53, 67, 82}

- The National Radiotherapy Advisory Group of the United Kingdom provides the view, based on the 'experience of those working in large centres', that a maximum of six to eight linacs is optimal. One linac only services are not supported given their potential impact on patient treatment should the machine be unexpectedly out of action. Minimum size for providing 'whole' service (simulation, planning and treatment) should be three to four linacs, still with links to a larger centre for specialised treatments. Within the UK context, their planning recommendation is four to eight linacs per department.⁵²
- In Australia no centre is planned to have more than eight linacs in one location.^{56, 62, 80}
- In Australia the largest numbers of bunkers are at the Peter MacCallum facility, this may be matched by developments at Royal Brisbane and Women's Hospital with plans to expand over time to seven to eight linear accelerators.^{62, 80}
- The majority of public units in Australia have between two to four linacs. In a 2009 survey, almost half of all facilities (48.9%) had only two linear accelerators, and another 11 facilities (24.4%) had just three linacs in service.^{40, 56, 62, 80}

Optimal workloads and throughput targets

- A key factor to consider in the siting of linacs is ensuring that departments have a sufficient workload to make them viable to run. The importance of justifying that additional treatment capacity is warranted has also been recognised in the Australian context.⁹
- There are published benchmarks for accelerator throughput, these benchmarks are most often used to estimate the number of linear accelerators per million people required to facilitate appropriate radiotherapy utilisation rates in each country.^{10, 19, 40, 53, 78}
- The Basic Treatment Equivalent (BTE) developed in Australia, remains the best measure of linear accelerator throughput.²¹
- Variations in radiotherapy provision affect the utilisation of this treatment modality. In several EU countries inadequate provision of radiotherapy resulted in long waiting times and poorer treatment outcomes.¹⁰
- The Swedish SBU study reported actual average annual throughput per unit in Sweden in 2001 was 338 treatment courses with a variation among centres ranging from 248 to 442. There was a high correlation between the number of linear accelerators and the volume of fractions of radiotherapy, which suggests the occurrence of certain economies of scale in Swedish external radiotherapy.^{10, 53}
- From the Australian ROJIG parameters, the maximum capacity for a linear accelerator is 414 courses of treatment per year, consisting of 331 new patients and 83 patients (25% of 331) being re-treated. These parameters remain unchanged since their issue in 2003.⁶³
- Planning for optimal machine configuration should consider unplanned downtime that increases with machine age and replacement of old machines which can take up to approximately four months. It is advisable to factor the workload generated from non-notifiable diseases (about 10% of treatments) and the complexity of treatment required for certain cancers.⁴⁶
- Changes in work practices offer the possibility of treating more patients for a given amount of resources or time and may be an important aid to improving patient access.^{9, 13}
- Technological and clinical advances resulting in increasingly complex, multi-field treatments are becoming more common in the clinical environment, for example, intensity modulated radiotherapy (IMRT), intra-operative radiotherapy (IORT) and high dose rate (HDR) brachytherapy.^{17, 43}

Workforce availability and engagement

- The constraints generated by limitations in the availability of an appropriately trained workforce is frequently mentioned in both the academic and practice literature.^{9, 8, 44, 45, 46, 61, 72}
- Larger centres may have economies of scale, particularly in relation to staffing.²⁵

- Developing radiation oncology services in areas distant to major population centres is often not possible for reasons such as an inability to attract sufficient numbers of specialist staff, insufficient caseload to justify a stand-alone service, or insufficient support or expertise at the local hospital to manage and operate such a specialist service.²⁵
- The Victorian SMU evaluation found that SMU staff were happy to work in smaller, team-oriented and less bureaucratic environments than hubs; however professional development was an area that required improvement.⁷⁹
- This hub and spoke or 'networked' service model provides the opportunity for cross-appointment of staff, leave cover and peer review.⁷
- Advanced or extended scope practice in radiation therapy is an accepted role in the UK and Canada. These positions allow radiation therapists to specialise in technical and holistic aspects of patient management.²

Geographic access

- Improvements in access and equity to radiotherapy services are required in both Australia and New Zealand in order to achieve the recommended 52.3% treatment rate.⁴⁶
- Distance and waiting times have been found to be a significant disincentive to having prolonged radiation therapy.^{1, 6, 11, 15, 33, 39, 42, 68,}
- Patients who lived further from regional cancer centres are less likely to receive radiation. This finding has been mirrored for differing cancers in other countries.^{9, 20, 24, 34, 58}
- Patients trying to access radiotherapy may experience psychological trauma, financial outlays and extended travel times.^{12, 36, 46}
- Specific themes identified in two Australian papers were: being away from loved ones, maintaining responsibilities whilst undergoing treatment, emotional stress, burden on significant others, choice about radiotherapy as a treatment, travel and accommodation, and financial burden.^{36, 42}
- In the UK patient surveys have indicated that there is substantial reluctance to accept daily travelling times of longer than 45 minutes each way. A drive time analysis for radiotherapy has shown that 87% of the population already live within 45 minutes of a radiotherapy centre. In England, the situation is very different to Australia, with 94% of the English population living within 50 km from their nearest Radiotherapy Centre.⁵⁰
- An economic evaluation (based on Canadian data), found that from a societal cost perspective only, that outreach radiotherapy (central comprehensive facility and satellite) is the economically superior model for separations between 30km and 170km. Beyond 170 km, a fully decentralised service would be warranted if the only consideration were societal economic advantage.²⁸
- The move towards a satellite or outreach model has been identified in Norway, Sweden, Canada and the UK, as one way of improving geographic access.¹²
- This is a growing trend in Australia where the dependence on large cancer centres such as the Queensland Radium Institute and the Peter MacCallum Cancer Institute in Melbourne are giving way to more city centres and satellite centres, particularly in country locations.⁴⁷
- Rural access has improved with new departments in Bendigo, Ballarat, Traralgon, Port Macquarie, Coffs Harbour and Toowoomba plus others planned for Orange, Lismore, Gold Coast, Cairns, Darwin and Bunbury.^{46, 56, 62, 80}
- The NSW Department of Health (2010) 'Radiotherapy Services in NSW Strategic Plan to 2016' details the NSW locations funded by both NSW and under the Commonwealth Government Health and Hospital Fund Regional Cancer Centre Initiative announced in April 2010. In summary, this has led to the funding of two bunker, single machine units in Tamworth and Nowra and a two linear accelerator unit in Gosford. A second linear accelerator has been funded for both Lismore and Port Macquarie and a third linear accelerator for Wollongong.⁵⁶

- The academic and practice literature shows the efforts of governments to balance better access to radiotherapy services through addressing the location of radiotherapy services, support for travel costs and patient accommodation.^{12, 42, 46, 50, 51, 58, 61}
- Whilst schemes exist to support patient travel and accommodation these are unable to keep pace with demand and the costs and impost of travel and costs of accommodation can be real barriers to radiotherapy access.⁴⁷
- Single machine units are a valid treatment option and capable of delivering care at an equivalent standard to that of larger comprehensive cancer centres. They improve access for patients and reduce transport and accommodation costs.^{14, 25, 27, 47, 69}
- Risks of a SMU include ‘...the challenges of clinical support, ease of referrals for complex or less common treatments, research, the inability to specialise, staff back-up arrangements, and the heavy impact in the event of a problem with the machine.’¹²
- The view most commonly expressed in the literature is that satellite centres may start as a single machine unit (SMU) but there are usually plans to expand to a two machine unit. There needs to be a formal link to a larger centre for clinical support, data collection, research and access to expertise for referral of less common cancers, often in a hub and spoke type arrangement.^{9, 15, 27, 31, 47, 61, 62, 79}
- As a model across Australia, the distance between hubs and spokes may limit the ability of SMUs to be effectively operated, serviced and maintained with integration from a hub centre. Within Victoria, no spoke was more than 2.5 hours by road from the hub, enabling travel within a single day between the hub and spoke.⁷⁹
- Cancer Council NSW recommends that preferred model for all centres is at least two machines, with single machine units only established where there are close geographic and service ties to another radiotherapy facility.¹²
- In NSW networking models are in place between Comprehensive Cancer Centres and satellites, for example, Westmead is linked with Nepean; Port Macquarie is linked with Coffs Harbour and Liverpool is linked with Campbelltown. New departments proposed for regional areas in NSW will be linked in a similar manner e.g. Illawarra and Shoalhaven.^{47, 56}

Quality and Safety

- Radiotherapy has a long history of quality assurance with an appropriate focus on radiation safety.^{17, 38, 75}
- Within the limits of our search of the literature we did not find any evidence of safety issues that are explicitly related to economies of scale and linac machine configurations.^{69, 79}
- The evaluation of the National Single Machine Unit Radiotherapy Trial previously referred to in Victoria, found the number of incidents per 100 courses reported at the regional centres of Bendigo and Ballarat were comparable with, or lower than, their hub services over the four years 2003 – 2006.⁷⁹
- There is significant variation in the ways in which centres manage their quality assurance and quality improvement activities.^{13, 40}
- The importance of a persistent safety conscious culture within radiotherapy departments is identified.⁷⁶
- As radiotherapy techniques become more complex it is difficult to rely on a manual checking process to detect and minimise errors. A rigorous ongoing quality assurance process is essential.¹⁷
- Treatment throughput cannot be assessed in isolation without any consideration for treatment quality, treatment outcomes and patient or staff satisfaction.^{7, 22}
- Advances in remote monitoring systems now offer opportunities to maintain technical quality while enhancing patient access. Telemedicine is another model that has proven beneficial in reducing the impact of extreme distance.^{64, 77}

- As more and more regional cancer centres are opened up there are certain types of complex cancers that are probably best treated in the major facilities. The difficulty is to reconcile the convenience of treatment in the regions with the impossibility of maintaining sub-specialty expertise in every small facility.^{64, 77}

Concluding Remarks

NSW Health should continue to monitor developments in radiotherapy, particularly if they impact upon costs, machine capacity, workload and throughput considerations, workforce availability, geographic access, quality and safety.

Determining the optimal machine configuration for centres must balance many competing factors - ultimately the quality of clinical outcomes is perhaps one of the most important criteria on which to base our judgement.

1 Literature review methodology

1.1 Introduction

The need to ensure efficient use of radiotherapy infrastructure is well recognised by NSW Health. In 2006/07, in conjunction with the Cancer Institute NSW (CI NSW), a Business Process Improvement (BPI) project was undertaken for radiotherapy services in NSW. This was completed in 2009. The BPI project has demonstrated that improvements in efficiencies can be realised with existing infrastructure with the improvements in operational processes.

In 2009, the NSW Audit Office conducted a Performance Audit of NSW radiotherapy service and recommended that NSW Health, 'assesses economies of scale to assist in considering the most cost effective linear accelerator machine configuration and the impact on access to services'. The NSW Department of Health therefore commissioned the Centre for Health Service Development (CHSD) to undertake a targeted literature review to continue to assist NSW Health in responding to this issue.

1.2 Context

Radiation treatment is one of the fundamental tools available in cancer treatment and one of the three cornerstones of multidisciplinary cancer care, along with chemotherapy and surgery as part of a quality comprehensive cancer service. Radiotherapy can be given in two ways, through external beam radiotherapy (which uses high energy machines) and brachytherapy (which uses radioisotopes). 'Megavoltage' treatments are an external beam radiotherapy, which is delivered by linear accelerators (Baume 2002). These machines are often referred to as linacs.

The treatment schedule usually requires several treatments over a period of days or weeks. This may be given in a single treatment or over a course of treatments (fractionation), typically, one treatment per day between Monday to Friday with the patient customarily managed as an outpatient (Faculty of Radiation Oncology 2002; Conforti, Guerriero et al. 2008). Advances in technology and imaging have led to the development of sophisticated radiotherapy planning and treatment techniques (Symonds 2001). Radiotherapy is often seen as an expensive high-tech treatment. However, both Australian and international data show that generally, it is one of the most cost-effective forms of cancer treatment (Delaney, Sorensen et al. 2002; Norlund 2003; Ploquin and Dunscombe 2008; Morgan, Barton et al. 2010).

The location of radiotherapy services is influenced by a complex range of factors and consequently requires a comprehensive service development process which incorporates clinical support services and other population demand factors (Statewide Services Development Branch: NSW Health Department 2002). In addition, there are multiple roles and responsibilities relating to cancer care across the NSW Department of Health; Area Health Services; the Cancer Institute NSW, as well as at the Commonwealth Government level (NSW Department of Health 2010).

We recognise there have been a number of reviews to better understand the key issues in radiotherapy service provision, arguably the most influential is '*A Vision for Radiotherapy: Report of the Radiation Oncology Inquiry*' released in 2002 (Baume 2002). This report and subsequent studies have addressed the issue of single machine units in Australia (Baume 2002; Department of Health:Victorian Government 2009; Department of Health and Ageing and the Victorian Department of Human Services Undated; Victorian Department of Human Services Undated). However the assessment of optimal machine configurations has had limited attention and this is the focus of this targeted literature review.

1.3 Search strategy

Our approach is based on purposive literature review techniques. CHSD has developed a best practice literature search methodology to find key articles/documents from the academic and practice literature (both national and international). This methodology is based on state-of-the-art guidelines for health technology assessments and systematic reviews of the literature (Alderson, Green et al. 2005). This search methodology has a number of drills and layers to ensure optimal coverage of the academic and practice literature within the scope of our brief.

The US National Library of Medicine's MeSH terminology was used to generate search terms which were then used in various combinations. These search terms were entered into several databases. Initially searching focused on core clinical journals with the aim of identifying systematic reviews. Known sources of systematic reviews such as the Cochrane Library, Database of Abstracts of Reviews of Effects (DARE) and the Turning Research into Practice (TRIP) database for Evidence Based Medicine were individually searched using a range of MeSH headings in combination. Our approach is summarised below.

Academic literature

- Scientific literature searches (e.g. MEDLINE/PubMed, CINAHL, PsycINFO, CINAHL)
- Evidence-based health care search (e.g. Cochrane Library, DARE and TRIP databases, Health Reference Center)

Practice literature

- National libraries (National Library of Australia, US National Library of Medicine)
- Commercial web sites (e.g. AMAZON.com)
- Australian Government Department web sites (e.g. Commonwealth Department of Health and Ageing, State and Territory Health and Human Service Departments)
- Australian professional colleges and associations (e.g. Faculty of Radiation Oncology, Royal Australian and New Zealand College of Radiotherapists)
- International Government Department web sites in selected countries
- International professional colleges and associations relevant to the search strategy.

The search terms employed for this review are summarised in Table 1.

Initially the results from our primary search were not that promising and unsurprisingly the search term 'machine configuration' generated virtually nothing. We then widened our search terms with the most useful search terms in various combinations including: radiotherapy, radiation therapy, utilisation and efficiency.

The resulting citations were culled to exclude those that did not focus on a key aspect of utilisation such as costs, machine capacity, patient throughput, workforce availability, geographic access, safety or quality. Only English language citations were retained. Additional citations were identified by reviewing the reference lists in recently published works. We have made extensive use of Google Scholar to 'work forwards' in the literature and snowball searching to 'work backwards' in the literature. Whilst we focused on literature published between 2000 and 2010, in some cases we included older publications that contributed to our understanding of the key issues. In addition we identified Australian experts and purposively searched for their publications. We also identified key Australian journals, such as the *Journal of Imaging and Radiation Oncology* and hand-searched current publications' Table of Contents' to ensure we had identified the most recent and relevant material. A second round of culling was undertaken based on reading the abstract or executive summary of each paper. This methodology has revealed approximately 90 items. Where readily accessible, the full text copies of relevant papers/reports were reviewed.

In addition we surveyed a wide range of practice or ‘grey’ literature sites to identify relevant sources that may not have appeared in the published literature. We focused on health related government sites, professional associations as well as some recognised grey literature hubs.

Table 1 *Search strategy*

Academic Literature		Period	Primary Search Terms	Secondary Search Terms
Databases	<ul style="list-style-type: none"> ▪ MEDLINE ▪ PubMed ▪ CINAHL ▪ PsycINFO ▪ Rural and Remote Health ▪ Cochrane Library ▪ DARE ▪ TRIP ▪ Health Reference Center 	2000 - 2010	Radiotherapy Radiation Therapy Radiation Linac machine\$ Linear accelerator\$	Machine configuration Health Care Utili\$ation Utili\$ation Reviews Treatment Faciliti\$ Outpatient Treatment
Practice Literature		Period	Primary Search Terms	Secondary Search Terms
Web site domains	<ul style="list-style-type: none"> ▪ All Commonwealth and State government web-sites ▪ NZ Government ▪ UK Government ▪ US Government ▪ Canadian Government ▪ French Government ▪ Singapore Government ▪ Joanna Briggs Institute ▪ Royal Australian College of Radiation Oncology (equivalent professional associations in NZ, Canada, UK and US) ▪ Health Technology Assessment sites (international) ▪ Kaiser.edu.org ▪ Rand corporation ▪ IHI.org ▪ UK Policy Hub (http://www.nationalschool.gov.uk/policyhub/) ▪ NHS National Institute for Health and Clinical Excellence ▪ US National Center for Policy Analysis ▪ New York Academy of Medicine Grey Literature Report ▪ GreyNet – the Grey Literature Network Service ▪ WHO web-sites ▪ OECD web-sites 	2010	Linear accelerator\$ Radiotherapy treatment machine\$ Linac machine\$	Cost-effectiveness Delivery model\$ Efficiency Value for money Utilisation rate\$

2 Overview of the literature

2.1 Scope

From our primary search, we examined the literature to identify evidence relating to optimal machine configuration. The question we sought to answer was: is there an optimal machine configuration for the delivery of radiotherapy? There are very limited current publications that specifically address this issue, the recent single machine unit trial in Victoria, a notable exception.

Our expanded search strategy found the most useful literature focused on aspects of utilisation such as costs, machine capacity, optimal workloads and throughput targets, workforce availability, geographic access and to a lesser degree quality and safety. We were particularly looking for references to economies of scale.

2.2 Exclusions

Whilst there are diverse issues that impact upon radiotherapy services planning, many are outside the scope of this literature review (Postma and Terpstra 2000; Morgan, Barton et al. 2010; NSW Department of Health 2010). We have deliberately not addressed in detail the various models used to estimate the number of linacs required for given populations and treatment rates. It is not our role to make judgements about what actions may or may not be required but simply to present the evidence within the literature.

2.3 Schema for evaluating the evidence

The focus is on including the best available evidence. The strength of the evidence has been assessed through the use of the classification system shown in Figure 1. The first five levels are hierarchical and relate to the strength of the evidence on interventions. The last five have been used to summarise evidence on relevant aspects of radiotherapy utilisation.

Figure 1 *Schema for summarising the strength of the evidence*

1. **Well-supported practice** – evaluated with a prospective randomised controlled trial
2. **Supported practice** – evaluated with a control group and reported in a peer-reviewed publication
3. **Promising practice** – evaluated with a comparison group
4. **Acceptable practice** – evaluated with an independent assessment of outcomes, but no comparison group (e.g., pre- and post-testing, post-testing only, or qualitative methods) or historical comparison group (e.g., normative data)
5. **Emerging practice** – evaluated without an independent assessment of outcomes (e.g., formative evaluation, service evaluation conducted by host organisation)
6. **Profiles** of treatment population (e.g., routine data)
7. **Service planning parameters** (e.g., legislation, policy)
8. **Patients' views** (e.g., surveys, interviews)
9. **Expert opinion** (e.g., peak bodies, government policy)
10. **Economic evaluation** (including service utilisation studies)

This system of evaluating and summarising the evidence for interventions was designed at the CHSD and is based on hierarchies originally developed by other organisations. In its document on developing clinical practice guidelines, the National Health and Medical Research Council of Australia (National Health and Medical Research Council 1999) states that *'recommendations ... should be based on the best possible evidence of the link between the intervention and the clinical outcomes of interest'* (NHMRC, 1999). This requirement is equally important in the field of social

and educational interventions, where the goals of providing maximum benefit with minimum harm and acceptable cost also apply.

2.4 The academic literature

There is limited academic literature relating to optimal machine configurations for radiotherapy services. Within the scope of this review we found only two publications that focussed specifically on machine configurations for radiotherapy units. Both these papers reported on results from The National Radiotherapy Single Machine Unit Trial conducted in Ballarat, Bendigo and Traralgon in Victoria.

Randomised clinical trials are the gold standard for comparing technologies (Nystrom and Thwaites 2008). No systematic reviews were identified and similarly no randomised controlled trials were found. In fact, with regards to research design the quality of evidence is predominantly limited to an analysis of routine data collected from national minimum data sets or from routine data collected at single study sites. Several economic evaluations of radiotherapy have been conducted to demonstrate cost-effectiveness. The most recent of these conducted by Ploquin et al. (2008) is based on a review of 11 publications dated between 1981 and 2004. This analysis demonstrated that the real cost of radiotherapy over the last 15 years has risen by approximately 5.5%.

Overall, the majority of articles used for this review have a focus on the geographic location of radiotherapy units, the utilisation rates of radiotherapy services, the infrastructure required, the efficiency of radiotherapy units, their work-load patterns and costs. These articles came from a variety of journals. The most common sources are highlighted in Table 2 together with the number of articles that appeared in that particular journal.

Table 2 Journals generating most relevant academic literature

Journal	Country of origin	Number
Australasian Radiology/ Journal of Medical Imaging and Radiation Oncology	Australia	14
Radiotherapy and Oncology	Denmark	10
Clinical Oncology	United States	8
International Journal of Radiation Oncology-Biology-Physics	United States	7

The articles have a truly international flavour originating in a variety of countries. The most common source of papers was from Australia, followed by the United Kingdom, Europe, the United States and Canada. The most commonly cited Australian authors in this area were M. B. Barton and G. P. Delaney from the Collaboration for Cancer Outcomes Research Evaluation (CCORE) at the University of NSW and G. W. Morgan from the Faculty of Medicine also at the University of NSW.

Whilst just under half of the papers were published from 2006 onwards most of the papers refer to research undertaken at the beginning of the millennia. Our search limits specified academic literature published between 2000 and 2010; however we found some useful papers on efficiency considerations published during the 1990s which we included.

2.5 The practice literature

A search of the practice literature relating to radiotherapy identified Australia and the United Kingdom as most prolific in developing and publishing reports and material related to radiotherapy infrastructure and services planning. Europe has also been strong in producing literature relating to radiotherapy infrastructure and service provision; however, there were fewer reports and documents readily accessible among the practice literature.

While Canada and the United States were also strong in radiotherapy research and planning, there was more limited practice literature relating to radiotherapy infrastructure. Very little practice literature relating directly to radiotherapy infrastructure was found for countries in Asia or New Zealand.

Australian practice literature in radiotherapy has been stimulated by the Single Machine Unit Trial in Victoria and the Radiation Oncology Inquiry (Baume 2002). There are a number of State government based cancer and radiotherapy planning, service framework and review documents, particularly with focus on NSW and Victoria (Victorian Government Department of Human Services 2007; Queensland Health 2008; NSW Department of Health 2010). The Cancer Institute NSW (2009) has implemented a Radiotherapy Business Improvement Strategy which includes the significance of optimal process design in machine configuration. The Royal Australian and New Zealand College of Radiologists (2002) has also developed guidelines for clinicians working in radiation oncology. Dr. Geoff Delaney has been an influential Australian author in relation to radiotherapy service provision. In particular Dr Delaney was the first author for a report on estimating the optimal utilisation of radiotherapy in cancer care in Australia (Delaney, Jacob et al. 2003). The NSW Cancer Council has also produced a road map for improving radiotherapy services in NSW (NSW Cancer Council 2009). The Clinical Oncological Society of Australia and the Cancer Council Australia (2007) have also produced a paper relating to multidisciplinary cancer care in regional Australia and building centres of excellence in regional areas that includes recommendations for radiotherapy.

The United Kingdom has developed a number of excellent resources relating to radiotherapy capacity and infrastructure. The National Radiotherapy Advisory Group (NRAG) has produced several quality reports around radiotherapy infrastructure and services. These include a comprehensive report aimed at developing a world class radiotherapy service for England (National Radiotherapy Advisory Group 2007), a detailed report on capacity and efficiency in radiotherapy (National Radiotherapy Advisory Group United Kingdom 2006) and a report on predicting future demand for radiotherapy (National Radiotherapy Advisory Group 2007). The Royal College of Radiologists has also been active in developing guidelines in service planning. These include a guide to planning radiology services (Royal College of Radiologists 2008) and a report on equipment, workload and staffing for radiotherapy in the UK from 1997-2002 (Royal College of Radiologists 2005). A report by the National Health Service in Scotland outlines radiotherapy activity planning from 2011-2015 for Scotland (Scottish Executive Health Department 2005). The UK also has a number of broader cancer documents that provide information on radiotherapy practice, including the NHS Cancer Plan Progress Report (National Audit Office 2005) and a policy report on commissioning cancer services (Expert Advisory Group on Cancer to the Chief Medical Officers of England and Wales 1995).

Practice literature identified from European countries included mainly work done on the ESTRO QUARTS study and radiation safety reports. Radiotherapy planning in Europe has been characterised by the QUANTIFICATION of Radiation Therapy Infrastructure and Staffing Needs or QUARTS study that was undertaken in 2003-04 (Heeren, Slotman et al. 2004). This project was a survey of radiotherapy services in Europe.

Radiotherapy research in Canada has been lead by the organisation Cancer Care Ontario. This organisation has produced a report relating to access (Hanna 2009) as well as a web-based resource that gives up to date information on waiting times and radiation treatment utilisation and other aspects of radiotherapy services provision.¹ A search of the practice literature in the United States produced limited relevant material specific to optimal machine configuration, as did searches of the practice literature from New Zealand. Relevant practice literature was not identified for countries in Asia, including Singapore.

¹ Source: <http://csqi.cancercare.on.ca/cms/One.aspx?portalId=63405&pageId=65668> accessed 23 Sep 2010)

Internationally, the World Health Organisation has produced reports mainly about radiotherapy safety. Notably an independent report on the circumstances surrounding a serious adverse event in radiotherapy (Toft 2005) The WHO has also published a series of Cancer Control Guides for effective programmes, which includes an outline of radiotherapy infrastructure feasible for middle to low income countries (World Health Organisation 2008b). The International Atomic Energy Agency (2004; 2007) in Vienna has also produced reports about safety and quality in radiotherapy.

3 Findings

The major findings within the academic and practice literature are synthesised in this section of our report. We found the most useful literature focused on aspects of utilisation such as costs, machine capacity, optimal workloads and throughput targets, workforce availability, geographic access, quality and safety. In our view, it is this combination of factors that can best inform thinking about optimal machine configuration in radiotherapy planning to achieve economies of scale as the optimal size of a radiotherapy service has not been identified in the Australian context (Victorian Government Department of Human Services 2007, p.20)

3.1 Costs and economics

Radiotherapy continues to evolve with new technology and techniques widening the indications and options for therapeutic treatment and palliative care (Bentzen, Heeren et al. 2005; Nystrom and Thwaites 2008; Thwaites and Verellen 2010). The rapid and continuing advances in technology are resulting in a continuum of new developments, including new types of equipment and new applications of existing equipment. These new advances require careful and systematic evaluation and comprehensive quality assurance (Thwaites and Verellen 2010). Due to the highly specialised staff required to prescribe, plan and deliver radiotherapy as well as the required capital investment in treatment units and associated building stock, changing radiotherapy capacity requires long term planning and investment in education and infrastructure (Bentzen, Heeren et al. 2005; Victorian Government Department of Human Services 2007; NSW Department of Health 2010).

Despite radiotherapy being considered as the most cost-effective cancer treatment (Delaney, Sorensen et al. 2002; Nystrom and Thwaites 2008), governments continue to seek evidence that the capital investment required generates value for money (NSW Audit Office 2009). Morgan, Barton et al. (2009) in addressing radiotherapy planning requirements in NSW, identified that an additional 12 linear accelerators was estimated to cost \$200 million over four years for one-off establishment costs for buildings and equipment plus \$50 million per year for recurrent operating costs such as staff salaries. Whilst radiotherapy does require a large 'up-front' capital investment these costs are amortised over the ten-year machine life and radiotherapy is a cost-effective treatment option (Nystrom and Thwaites 2008; Ploquin and Dunscombe 2008; Morgan, Barton et al. 2010). In Australia, this ten-year machine life is a 'notional' life dictated by the Commonwealth, as after ten years machines no longer accrue Health Program Grants (HPG) funds. Extending accepted machine-life to twelve years has been canvassed in several countries (Baume 2002; National Radiotherapy Advisory Group 2007). Newer machines with more recent technological enhancements have been shown to generate higher throughput (Delaney, Shafiq et al. 2005).

Norland (2003) reported on a systematic assessment of radiotherapy for cancer conducted by 'The Swedish Council on Technology Assessment in Health Care' (SBU) in 2001. A questionnaire was sent to all 16 radiotherapy units in Sweden, with reporting requested on the year 2000. Four major aspects of radiotherapy were assessed: employees and competence, equipment, building area and statistics on the production volume. At this time only one single machine unit was reported at Jonkoping with a note 'plus one accelerator being replaced'. Of the remaining 15 units:

- five units had two linear accelerators per unit;
- four units had three linear accelerators per unit;
- two units had four linear accelerators each;
- one unit had five linear accelerators;
- one unit six linear accelerators;
- one unit had seven linear accelerators; and
- the largest unit in Stockholm (Karolinska) had eight linear accelerators.

The assessment included an overview of the capacity for radiotherapy in terms of infrastructure of cancer care and an estimation of the costs of radiotherapy in Sweden. The total cost of external radiation therapy was estimated in the year 2000 at approximately 5% of the estimated total cost of oncology care in Sweden. Calculations of the cost structure for radiotherapy were based on data from the questionnaire. Capital costs accounted for just over a fifth of total cost with capital equipment accounting for 20% and capital for buildings approximately 6.2% (Norlund 2003, p.413). A comparison was made with three other studies and this information is summarised in Table 3.

Table 3 *Comparison of cost structures for radiotherapy as reported by Norlund²*

Author	Smith	Daly-Schveitzer	Duncombe	This study
Year	1995	1995	1999	2000
Country	Australia	France	Great Britain	Sweden
Salaries, %	55	62	56	51
Capital, %	29	19	19	26
Other, %	16	19	25	23

Bentzen, Heeren et al. (2005) discuss the application of activity based costing in the context of radiotherapy cost-effectiveness, particularly the study of Leuven. The Leuven model demonstrated that even in this era of very sophisticated (and costly) radiotherapy equipment, personnel costs remain the most important cost component of a radiotherapy department, consuming about twice the budget of equipment (52% versus 28%). The cost of the final product is mainly determined by the length of the treatment (number of fractions) and by the daily treatment time. This means that departments should be of sufficient size to optimise cost-effectiveness. These are key factors to assess in considering optimal machine configurations. Within the Belgian context of Leuven's study, a lower threshold for department size was found to be around 1000 patients treated annually (Bentzen, Heeren et al. 2005).

Smaller facilities are seen to have an impact on the cost and cost-effectiveness of radiotherapy services. Baume (2002) reported on the 1988 study by Goddard and Hutton in the UK that estimated that the cost per field or course of treatment in a small department to be 33% more than a large department. Duncombe et al. (1999) used financial data from the Northeastern Ontario Regional Cancer Centre to investigate the economic effects of changes in selected operational parameters within a radiation treatment program. They concluded that the cost of radiotherapy in a facility treating less than 1600 patients per year starts to rise. 'At 400 patients per year, a course costs approximately 50% more than at 1600 patients per annum.' The authors (Duncombe, Roberts et al. 1999 pp.600-601) state that:

'The primary non-financial factors to be considered in the establishment of a small centre are (i) the practicality of patients being able to access a large centre particularly in sparsely populated regions such as Northern Ontario and (ii) patient convenience.'

The significant increase in cost below 1600 patients per year comes from underutilisation of ancillary equipment. The slow decrease in cost above 1600 patients results from the sharing of the cost of supervisory positions over a greater number of patients. On the basis of this model the authors found no significant economies of scale for facilities with more than four fully utilised treatment units.

Bentzen, Heeren et al. (2005) discuss the value in applying activity based costing methods to develop a costing model. They argue that models developed at the department level are not easily extrapolated to other countries or health care systems and therefore costing models should be developed at a supra-institutional, international level. Such a costing model would yield the necessary cost data to perform economic evaluations of new treatment strategies and potentially analyses relating to scale. An accurate cost accounting model, yielding insight into the cost structure of the department and its delivered products, may be used to evaluate the financial

² Refer to, Norlund for the SBU Survey Group (2003) *Costs of Radiotherapy*. Acta Oncologica, Vol. 42, No. 5/6, pp.411-415.

consequences of practice change and thus support strategic planning at the department level (Lievens and Slotman 2003). Within this context, it is interesting to note that NSW Health has recently commissioned a costing study of Radiation Oncology Treatment Centres in NSW.³

The Evaluation of the National Single Machine Unit (SMU) Radiotherapy Trial conducted in Victoria commenced in 2003. The evaluation included information on the costs and economics of SMUs. The additional costs of providing treatment at the SMUs compared to the hubs ranged from \$0.2 to \$1.3 million per annum. Costs per course at the regional centre of Ballarat were between 19-36 per cent higher than the metropolitan hub, at the Austin. The higher uptake of IMRT at this centre may have been a factor. Activity levels at all centres most significantly impacted on cost per course (Victorian Department of Human Services Undated).

Poulson, Middleton et al. (2010) have recently published a comparative analysis of a Commonwealth-initiative regional radiation oncology facility in Toowoomba with a Queensland health facility. The comparison concentrated on staffing, casemix, and operational budgets but was not able to look at changes in access to services. The average Medicare cost per treatment course was similar in both centres (\$5000 per course). Total costs of an average treatment including patient, State and Commonwealth costs, showed a 30% difference in costing favouring Toowoomba. Most of this difference is reflected in the staffing levels. It is not clear from the article whether both facilities operated under the same quality and safety conditions.

Postma and Terpstra (2000) recognise that economies of scale can be realised by concentration of facilities (equipment and manpower) which may result in a more efficient and cost-effective input and use of resources. However they also discuss 'economies of scope' which can be realised because of the complementarity of radiotherapy as a treatment modality with other treatment modalities, this in turn generates a demand for a certain level of hospital infrastructure. This is a similar approach to the use of 'Role Delineation Guidelines' in service planning (Statewide Services Development Branch: NSW Health Department 2002).

3.2 Machine capacity

Norlund (2003) recognised that the utilisation of equipment offers the potential to achieve economies of scale. The author reported on the relationship between number of accelerators and number of fractions at specific departments and the number of fractions as a function of the number of accelerators. There was no tendency in the model that might indicate any threshold effects in external radiotherapy. A simple regression analysis showed a high correlation between equipment capacity and degree of utilisation. A high correlation was also found between input of manpower and output of fractions in the Swedish departments of radiotherapy.

Models to predict the number of linear accelerators (linacs) required usually assume that capacity needs to equal demand, to avoid the build-up of waiting times. Queuing theory is a branch of applied mathematics that looks at the relationship between waiting time, service time and utilisation (Conforti, Guerriero et al. 2008). Thomas (2003) reports on several studies that have shown that maximum acceptable percentage utilisations are between 85-95% depending on the number of matched linacs and on the maximum acceptable delay. He presents a method of estimating the maximum percentage use required to keep waiting lists low and uses this method to generate calculations of the number of linacs required per million population. Thomas (2003, p. 354) defines utilisation as the mean number of hours used per day divided by the mean number of hours available, and is equal to the ratio of mean demand to capacity. Thomas's (2003) modelling completed in the UK demonstrates that for a given level of demand, capacity needs to be about 10% greater to avoid queues, (a key assumption being that 86% of patients are able to start radiotherapy within a week of completing the treatment planning process). The level of excess capacity required depends on whether the machine is run as a single machine or as part of a matched pair, with the routine ability to move patients between machines.

³ RFQ Costing of the Public Radiation Oncology Treatment Services in NSW, July 2010.

Thomas (2003) concludes that linear accelerators cannot be run at average utilisations in excess of 90% without causing delays to patients' treatments as a result of random fluctuations in demand. Machines run as stand-alone units, rather than operating a single queue with a matched machine need to be run at even lower utilisations to avoid delays. This practice may not occur in all units with two or more linacs.

We looked for references to machine numbers and the maximum number of linacs found in the academic literature was eight in a major Swedish treatment centre but this data was from 2000. In 2002, the Canadian Province of Ontario with 65% of Australia's population, organised itself around nine centres with eight linacs in each (Baume 2002). Recent information suggests that the largest number of linacs found in one centre is at the Odette Cancer Centre (13 linacs) and the Princess Margaret Hospital (17 linacs) both within the Toronto Central Region of Canada (Toronto Central Regional Cancer Program, undated). A review of the web identified 11 linacs at The Beatson West of Scotland Cancer Centre in Glasgow, which deliver over 300 radiotherapy treatments per day⁴, (information on daily hours of operation was not available). The Scottish Executive Health Department (2005) states that by 2007-2008 linear accelerators will be publicly available through five cancer centres (Glasgow is the largest with 11, Edinburgh with 6, Dundee 3, Aberdeen 3 and Inverness 2).

The National Radiotherapy Advisory Group of the United Kingdom (2006, p.7) has produced a report that provides recommendations on a range of aspects of radiotherapy service provision. They provide the view, based on the 'experience of those working in large centres', that a maximum of six to eight linacs is optimal.

'...The minimum size for providing a radiotherapy department should be two linacs (i.e. one linac only services are not supported given the potential impact on patient treatment should the machine be unexpectedly out of action...Minimum size for providing "whole" service (simulation, planning and treatment) should be three-four linacs, still with links to a larger centre for specialised treatments (Total Body Irradiation... etc)'. The planning recommendation is four – eight linacs per department.'

Esco et al. (2003, p. 320) describe a survey conducted by the 'Spanish Society of Radiotherapy and Oncology' which gathered data from all public and private radiation oncology services in Spain. The data was for the year 1999 and included 84 centres, with 57 public centres and 27 privately managed. Machine configurations were as follows:

'Of the 84 centres in the census, 39% had one megavoltage unit exclusively, 43% had two, and 12% had three; four and five units were found in 2.4% and 3.6%, respectively'.

The largest number of bunkers in an Australian cancer centre totals six at the Peter MacCallum Cancer Centre in East Melbourne (Victorian Government Department of Human Services 2007; NSW Department of Health 2010). In Queensland, there are fewer public radiotherapy centres and numbers of linear accelerators per centre range between three to five per centre. Queensland Health's long term plan will result in more public radiotherapy centres the largest will be at Royal Brisbane and Women's Hospital with seven to eight linear accelerators projected by 2017. During this time several two linac services will be developed potentially in Cairns, the Sunshine Coast, Gold Coast and Redcliffe. The Gold Coast service will have space for five bunkers (Queensland Health 2008). The strategic plan for NSW 'Radiotherapy Services in NSW Strategic Plan to 2016' (NSW Department of Health 2010), identifies the largest services with five linear accelerators at Royal Prince Alfred Hospital and Calvary Mater Newcastle. The majority of public units in NSW have between two to three linear accelerators.

Kolybaba (2009) conducted a survey of all facilities providing radiation treatment services in Australia (n=45), information was received from 42 sites by June 2006. Almost half of all facilities

⁴ http://www.beatson.scot.nhs.uk/content/default.asp?page=s22_1

(48.9%) had only two linear accelerators, and another 11 facilities (24.4%) had just three linacs in service.

Table 4 *Total number of machines at radiotherapy facilities from Kolybaba survey*

	Number	%	Cumulative %
Single machine facilities	5	11.1	11.1
Two linac facilities	22	48.9	60.0
Three linac facilities	11	24.4	84.4
Four linac facilities	4	8.9	93.3
Five linac facilities	3	6.7	100
Total facilities	45	100	-

3.3 Optimal workloads and throughput targets

The Report to Ministers from the National Radiotherapy Advisory Group (2007) entitled 'Radiotherapy: developing a world class service for England' specifies that a key factor to consider in the siting of linacs is ensuring that departments have a sufficient workload to make them viable to run. The importance of justifying that additional treatment capacity is warranted has also been recognised in the Australian context (Baume 2002).

Linear accelerator throughput is quantified as the number of treatment courses per year. This will vary with a multitude of factors including the complexity of delivered treatments, number of fields, number of dose fractions, extent of quality assurance procedures, efficiency of equipment and staff. Most of these factors vary with tumour type, stage of disease and the performance status of the patient (Bentzen, Heeren et al. 2005).

Postma and Terpstra (2000) provide a simplified capacity/needs model to explain what drives demand for linear accelerators, they state that the interplay between demography and epidemiology (incidence and prevalence) coupled with technological and therapeutic developments generates service demand from new and recurrent patients and also new radiotherapy patients.

Norlund (2003) provided statistics on radiotherapy throughput from an assessment conducted by The Swedish Council on Technology Assessment in Health Care (SBU) in 2001.

During the 1990s there was an increase in external radiotherapy by 37% in terms of fractions, by 41% in terms of patients and by 55% in terms of fields. In the same period the number of fractions per accelerator increased by about 20%.

This increase of efficiency in the late 1990s was ascribed in part to a gradual increase in the automation and computerisation of external radiotherapy in Sweden. Delaney et al. (2005) provide a comprehensive explanation of the 'Basic Treatment Equivalent' (BTE) model developed in 1996 and subsequently refined in 2005. Their study, based in NSW, included 27 linear accelerators across 13 departments for a total of 135 days of linear accelerator operation in an attempt to improve the measurement of linear accelerator throughput. They identified and measured, 19 different factors influencing fraction duration. The authors were able to identify improvements to the 1996 BTE model and concluded that BTE remains the best measure of linear accelerator throughput.

There are published benchmarks for accelerator throughput, these benchmarks are most often used to estimate the number of linear accelerators per million people required to facilitate appropriate radiotherapy utilisation rates in each country. There is considerable interest in benchmarking the relative performance of radiotherapy treatment centres (Kolybaba 2009; van Lent, Beer et al. 2010). Bentzen, Heeren et al. (2005) report on the ESTRO QUARTS project which developed a model based on epidemiological data and evidence based indications for radiotherapy and compared model estimates with current levels of radiotherapy infrastructure for 25 EU countries. Their analysis of the UK suggested that variations in radiotherapy provision affect the utilisation of this treatment modality. In several EU countries inadequate provision of radiotherapy resulted in long waiting times and poorer treatment outcomes.

Austria, Ireland, Netherlands, Czech Republic, Poland and Slovakia had a defined benchmark for linear accelerator throughput which varied between 400-600 treatments per year. The exception was Italy with a benchmark of 200-500 new treatments per year depending on patient category. In Sweden 300 treatments per unit per year was reported as the standard benchmark in 1996 but this was at the low end of the range of actual throughputs per unit in the 2001 SBU audit. A Dutch study used a benchmark of 500 treatments per year whereas actual throughput was reported around 410 treatments per year. A benchmark value of 450 treatment courses per year was used by the Collaboration for Cancer Outcomes Research and Evaluation (CCORE), (Norlund 2003; Bentzen, Heeren et al. 2005 p.358; Delaney, Jacob et al. 2005). The Swedish SBU study reported actual average annual throughput per unit in Sweden in 2001 was 338 treatment courses with a variation among centres ranging from 248 to 442. There was a high correlation between the number of linear accelerators and the volume of fractions of radiotherapy, which suggests the occurrence of certain economies of scale in Swedish external radiotherapy (Norlund 2003). This suggests that treatment units may be more efficiently utilised in larger departments (Bentzen, Heeren et al. 2005). The QUARTS group decided to use 450 treatments per megavoltage unit per year as a throughput target.

Machine throughput is a key parameter used to plan for radiotherapy services (Barbera, Jackson et al. 2003; Department of Human Services 2008; NSW Department of Health 2009; Morgan, Barton et al. 2010; NSW Department of Health 2010). Literature is readily accessible that describes optimisation models for efficient outpatient scheduling within a radiotherapy department (Delaney, Shafiq et al. 2005; Conforti, Guerriero et al. 2008).

The Australian Radiation Oncology Jurisdictional Implementation Group (ROJIG) planning parameters for linear accelerator capacity are as follows:

- 4.1 attendances per hour;
- 8 operating hours per day⁵;
- 240 working days per annum;
- 25% re-treatment rate (Radiation Oncology Jurisdictional Implementation Group 2003).

From the ROJIG parameters, the maximum capacity for a linear accelerator is 414 courses of treatment per year⁶, consisting of 331 new patients and 83 patients (25% of 331) being re-treated.

Morgan, Barton et al. (2010) caution against the use of a 'one-size-fits-all' approach in estimating a standard linac day or treatment capacity as this does not take into account the fact that not all departments achieve the 414 treatments per year or operate for the 1920 hours determined by the ROJIG formulae. In NSW in 2008, only 18 of 42 linear accelerators delivered more than 414 courses of treatment, and only those departments that delivered more than 414 courses operated for more than 1920 hours per linear accelerator (Morgan, Barton et al. 2010).

⁵ Victoria has different award agreements and operates on 8.5 operating hours per day.

⁶ Victoria radiotherapy planning adjusts this parameter to 450 courses of treatment per year for a linear accelerator. Victorian Government Department of Human Services (2007). Victorian Radiotherapy Service Plan. Metropolitan Health and Aged Care Services Division. Melbourne, Victorian Government Department of Human Services..

Planning for optimal machine configuration should consider unplanned downtime that increases with machine age and replacement of old machines which can take up to six months. It is advisable to factor the workload generated from non-notifiable diseases (about 10% of treatments) and the complexity of treatment required for certain cancers (Morgan, Barton et al. 2010).

Morgan, Barton et al. (2009 p.423) provide a comprehensive summary of the reasons why the total number of patients treated per linear accelerator per year may vary, this may be due to:

- Operating hours per day (dependant on staff)
- Number of working days (dependent on maintenance schedule)
- The re-treatment rate (increases with the age of department and numbers on follow-up)
- Unplanned down-time (increases with machine age)
- Staff experience (longer treatment times with less experienced staff)
- Student training (longer treatment times)
- Complexity of treatment (longer treatment times for paediatrics requiring general anaesthesia, total body irradiation and stereotactic radiosurgery) and;
- Research projects on linear accelerators.

The information included in the '2008 Radiotherapy Management Information System Report' (NSW Department of Health 2009) provides insight into the several of these factors in the context of NSW. Other issues that may affect the workload and productivity of linear accelerators across departments include, teaching radiation therapy students, quality assurance procedures and general administrative duties (Delaney, Shafiq et al. 2005).

Changes in work practices offer the possibility of treating more patients for a given amount of resources or time and may be an important aid to improving patient access (Baume 2002; Cancer Institute NSW 2009). This needs to be considered in tandem with the technological and clinical advances resulting in increasingly complex, multi-field treatments becoming more common in the clinical environment, for example, intensity modulated radiotherapy (IMRT), intra-operative radiotherapy (IORT) and high dose rate (HDR) brachytherapy (Commonwealth of Australia 2008; Mayles 2010).

3.4 Workforce availability and engagement

A report of the Scenario Sub-Group of the UK National Radiotherapy Advisory Group discusses siting issues for future linear accelerator developments noting that 'larger centres may have economies of scale, particularly in relation to staffing' (National Radiotherapy Advisory Group 2007).

The constraints generated by limitations in the availability of an appropriately trained workforce is frequently mentioned in both academic and practice literature (Baume 2002; Barton and Thode 2010; Mills, Thornewill et al. 2010; Poulson, Middleton et al. 2010; Tasmanian Department of Health and Human Services Undated). For example, the 'Cancer Control and Workforce Stock take and Needs Assessment' describes the present and future requirements for linear accelerators and staff in New Zealand (Ministry of Health 2007; Morgan, Barton et al. 2010).

The workforce groups required in radiotherapy centres include:

- Radiation Oncologists
- Radiation Therapists
- Radiation Oncology Medical Physicists
- Administrative Staff

- Para-Medical Staff (Morgan, Barton et al. 2009)

Developing radiation oncology services in areas distant to major population centres is often not possible for reasons such as an inability to attract sufficient numbers of specialist staff, insufficient caseload to justify a stand-alone service, or insufficient support or expertise at the local hospital to manage and operate such a specialist service (Department of Health and Ageing and the Victorian Department of Human Services Undated). The Victorian SMU evaluation found that SMU staff were happy to work in smaller, team-oriented and less bureaucratic environments than hubs, however professional development was an area that required improvement and commitment to address (Victorian Department of Human Services Undated, Undated)). This hub and spoke or 'networked' service model provides the opportunity for cross-appointment of staff, leave cover and peer review (Barton 2002).

The Clinical Oncological Society of Australia has provided a listing of the recommended staffing and services for a regional cancer centre of excellence (Clinical Oncological Society of Australia and The Cancer Council of Australia 2007).

A comprehensive analysis of advanced practice in diagnostic imaging and radiation therapy was released by the Australian Institute of Radiography in May 2009 (Australian Institute of Radiography Advanced Practice Working Group 2009). The report emphasises the need to develop a model that fits the unique circumstances of the Australian health system and that will meet future demand for high quality medical imaging and radiation therapy services.

The Office of the Allied Health Adviser, ACT Health, (2009) has recently released a report considering the evidence relating to extended scope of practice in radiation therapy. Advanced or extended scope practice in radiation therapy is an accepted role in the UK and Canada. These positions allow radiation therapists to specialise in technical and holistic aspects of patient management. This issue is being considered as the findings from the ACT Health radiation therapy survey highlight low morale and poor job satisfaction as being a particular issue in the ACT, advanced practice in radiation therapy may address some of these concerns.

3.5 Geographic access

Several published studies and policy documents address methods for estimating the number of linear accelerators required to achieve specific treatment rates and the implications for radiotherapy planning, evidence based practice and health outcomes if these service gaps are not closed (Delaney, Jacob et al. 2003; National Radiotherapy Advisory Group 2007; Morgan, Barton et al. 2010). Improvements in access and equity to radiotherapy services are required in both Australia and New Zealand, according to a study completed by Morgan, Barton et al. (2010), in order to achieve the recommended 52.3% treatment rate.

There is a need to attain a balance between the size of a facility and patient access (Baume 2002). Distance has been found to be a significant disincentive to having prolonged radiation therapy (ACIL Consulting Pty Ltd 1998; Barton 2000; Martin-McDonald, Rogers-Clark et al. 2003; Jong, Smith et al. 2004; French, McGahan et al. 2006; Clinical Oncological Society of Australia and The Cancer Council of Australia 2007) as are long waiting lists (Seel and Foroudi 2002; Board of the Faculty of Clinical Oncology - The Royal College of Radiologists 2004). The relationship between better access and increased utilisation of radiotherapy has been described in previous studies (Denham 1995; Delaney, Jacob et al. 2003; Pagano, Di Cuonzo et al. 2007).

The academic and practice literature shows the efforts of governments to balance better access to radiotherapy services through addressing the location of radiotherapy services, support for travel costs and patient accommodation (Martin-McDonald, Rogers-Clark et al. 2003; National Radiotherapy Advisory Group 2007; National Radiotherapy Advisory Group 2007; Pagano, Di Cuonzo et al. 2007; Cancer Council NSW 2009; Morgan, Barton et al. 2010; Poulson, Middleton et al. 2010).

A further Cancer Council paper 'Roadblocks to radiotherapy – Stories behind the statistics' in November 2009 documented the psychological trauma and financial outlays experienced by patients trying to access radiotherapy (NSW Cancer Council 2009; Morgan, Barton et al. 2010). Travel for radiotherapy places an extra burden on families already undergoing severe stress related to their cancer diagnosis and treatment (Hegney, Rogers-Clark et al. 2005). Martin-McDonald et al. (2003) conducted semi-structured interviews with 46 participants exploring issues relating to rural and regional people with cancer being treated in a metropolitan centre. Specific themes identified were: being away from loved ones, maintaining responsibilities whilst undergoing treatment, emotional stress, burden on significant others, choice about radiotherapy as a treatment, travel and accommodation, and financial burden. Hegney (2005) found similar findings in a small qualitative study based on the experiences of 17 rural people travelling from the regional city of Toowoomba to Brisbane. Hanna (2009) completed a retrospective population-based cohort study of factors affecting access to radiotherapy for endometrial cancer in Ontario, Canada. This large study of 9,411 women was drawn from the period 1992 – 2003. Patients who lived further from regional cancer centres were less likely to receive radiation. This finding has been mirrored for differing cancers in other countries (Baume 2002; Cancer Council NSW 2009).

The UK Report to Ministers from the National Radiotherapy Advisory Group (2007) entitled 'Radiotherapy: developing a world class service for England', discusses equity of access as ensuring that there is sufficient spread of linacs across the country. One issue to consider in relation to this is travel times. This Group reports that patient surveys have indicated that there is substantial reluctance to accept daily travelling times of longer than 45 minutes each way. A drive time analysis for radiotherapy has shown that 87% of the population already live within 45 minutes of a radiotherapy centre. In England, the situation is very different to Australia, with 94% of the English population living within 50 km from their nearest Radiotherapy Centre.

Morgan, Barton et al. (2010) provide the most recent Australian information on the distribution of rural radiotherapy centres, and note that rural access has improved with new departments in Bendigo, Ballarat, Traralgon, Port Macquarie, Coffs Harbour and Toowoomba plus others planned for Orange, Lismore, Gold Coast, Cairns, Darwin and Bunbury. The NSW Department of Health (2010) 'Radiotherapy Services in NSW Strategic Plan to 2016' details the NSW locations funded under the Commonwealth Government Health and Hospital Fund Regional Cancer Centre Initiative announced in April 2010. In summary, this has led to the funding of two bunker, single machine units in Tamworth and Nowra and a two linear accelerator unit in Gosford. A second linear accelerator has been funded for both Lismore and Port Macquarie and a third linear accelerator for Wollongong.

Morgan, Barton et al. (2009) comment that ease of access is invariably overlooked as a significant factor for the low treatment rates for radiotherapy. Whilst schemes exist to support patient travel and accommodation these are unable to keep pace with demand and the costs and impost of travel and costs of accommodation can be real barriers to radiotherapy access. They discuss a growing trend in Australia where the dependence on large cancer centres such as the Queensland Radium Institute and the Peter MacCallum Cancer Institute in Melbourne are giving way to more city centres and satellite centres, particularly in country locations. They argue that these additional centres improve access by providing treatment closer to home with less cost to patients and the broader health system for travel and accommodation expenses.

Duncombe and Roberts (2001) reached similar conclusions that satellite centres should be established to improve access and reduce the burden of transport and accommodation costs. In their economic evaluation (based on Canadian data), they state that from a societal cost perspective only, that outreach radiotherapy (central comprehensive facility and satellite) is the economically superior model for separations between 30km and 170km. Beyond 170 km, a fully decentralised service would be warranted if the only consideration were societal economic advantage. There is a footnote to their study which notes:

'Towards the end of this project the Ontario Ministry for Health announced approval for the construction of a single machine, treatment delivery satellite facility of the Northeastern Ontario Regional Cancer Centre, Sudbury, to be constructed in Sault Saint Marie. Sault

Saint Marie is 300km from Sudbury and serves a population of 137,000, 80% of whom live within 40km of the proposed site of the treatment facility' (Duncombe and Roberts 2001 p.35).

The move towards a satellite or outreach model has been identified in Norway, Sweden, Canada and the UK (Cancer Council NSW 2009). A report by the Board of the Faculty of Clinical Oncology – The Royal College of Radiologists (2004) includes a brief review of the international and national literature on the development of linked units (also referred to as satellite or 'hub and spoke' services). The view most commonly expressed in the literature is that satellite centres may start as a single machine unit (SMU) but there are usually plans to expand to a two machine unit. There needs to be a formal link to a larger centre for clinical support, data collection, research and access to expertise for referral of less common cancers, often in a hub and spoke type arrangement (Expert Advisory Group on Cancer to the Chief Medical Officers of England and Wales 1995; Baume 2002; Clinical Oncological Society of Australia and The Cancer Council of Australia 2007; Department of Human Services 2008; Morgan, Barton et al. 2009; Poulson, Middleton et al. 2010; Department of Health and Ageing and the Victorian Department of Human Services (Undated)).

Queensland Health (2008) state in the 'Queensland Statewide Cancer Treatment Services Plan':

'Stand-alone single machine unit (SMU) facilities are not supported as a general rule, but if considered necessary must be located sufficiently close to an existing service for back up and support. This principle will not necessarily apply where a designated service development involves staged introduction of linear accelerators.'

The SMU project in Victoria confirmed that SMUs were a valid treatment option and capable of delivering care at an equivalent standard to that of the Peter MacCallum Institute (Chapman, Shakespeare et al. 2007; Shakespeare, Turner et al. 2007; Department of Human Services 2008; Morgan, Barton et al. 2009; Department of Health and Ageing and the Victorian Department of Human Services (Undated)). The hub and spoke model achieved a balance between access, with services closer to home, and required workforce and professional expertise necessary to manage more complex cancers. The SMUs improved access to and uptake of radiotherapy in regional areas. Metropolitan hub service activity was impacted upon by the SMUs but continued to operate at acceptable levels. (Victorian Department of Human Services Undated). The 'Evaluation of the National SMU Radiotherapy Trial' specifies:

'As a model across Australia, the distance between hubs and spokes may limit the ability of SMUs to be effectively operated, serviced and maintained with integration from a hub centre. Within Victoria, no spoke was more than 2.5 hours by road from the hub, enabling travel within a single day between the hub and spoke, and facilitating hub and manufacturer back-up from metropolitan areas as required'(Victorian Department of Human Services Undated p.8)

Some of the risks associated with single machine units are summarised by the Cancer Council (2009, p.18) as follows:

'...the challenges of clinical support, ease of referrals for complex or less common treatments, research, the inability to specialise, staff back-up arrangements, and the heavy impact in the event of a problem with the machine.'

Cancer Council NSW recommends that the preferred model for all centres is at least two machines, with single machine units only established where there are close geographic and service ties to another radiotherapy facility.

In NSW networking models are in place between Comprehensive Cancer Centres and satellites, for example, Westmead is linked with Nepean; Port Macquarie is linked with Coffs Harbour and Liverpool is linked with Campbelltown. New departments proposed for regional areas in NSW will be linked in a similar manner (Morgan, Barton et al. 2009; NSW Department of Health 2010).

Morgan, Barton et al. (2009) conclude that increasing the number of linear accelerators in established departments and new satellite centres is a better way to correct service gaps in NSW, rather than working the current linear accelerators longer hours.

3.6 Quality and Safety

Radiotherapy has a long history of quality assurance with an appropriate focus on radiation safety (International Atomic Energy Agency 2007; Commonwealth of Australia 2008; Thwaites and Verellen 2010). A significant consideration around establishing radiation oncology services in regional areas is whether the quality of such a specialised health service can be maintained away from the typical environment of a high volume, metropolitan site (Department of Health and Ageing and the Victorian Department of Human Services Undated). Our search of the literature did not produce any safety issues that are explicitly related to economies of scale issues for linac machine configurations. The evaluation of the National Single Machine Unit Radiotherapy Trial previously referred to in Victoria, found the number of incidents per 100 courses reported at the regional centres of Bendigo and Ballarat were comparable with, or lower than, their hub services over the four years 2003 – 2006. No trends in incident reporting over time were observed. Radiation oncology safety requirements were adequate (Victorian Department of Human Services Undated). A planned evaluation of practice quality conducted with the four Victorian SMU sites found that SMUs provided as high a standard of radiotherapeutic care as larger hub departments. Service quality as measured by adherence to the RANZCR Peer Review Audit instrument was similar between SMUs and hub sites (Shakespeare, Turner et al. 2007).

Kolybaba's (2009) survey of 42 radiation treatment centres in Australia found that there was significant variation in the ways in which centres manage their quality assurance and quality improvement activities. The experience of the 'NSW Radiotherapy Business Improvement Process', similarly found that there were significant variations in a range of key performance indicators. Prior to the project only two centres were exceeding the planning benchmark of 414 courses of treatment per linear accelerator per year across all their linear accelerators. At the completion of all projects the participating centres averaged 411 courses per linear accelerator per year (Cancer Institute NSW 2009). A review of the '2008 Radiotherapy Management Information System Report' released in September 2009, suggests there is still variation between radiation oncology treatment centres (NSW Department of Health 2009).

The importance of a persistent safety conscious culture within radiotherapy departments is recognised in the practice literature (Toft 2005). As radiotherapy techniques become more complex it is difficult to rely on a manual checking process to detect and minimise errors. A rigorous ongoing quality assurance process is essential (Commonwealth of Australia 2008).

Roberts et al. (2002) argue that advances in remote monitoring systems now offer opportunities to maintain technical quality while enhancing patient access. Telemedicine is another model that has proven beneficial in reducing the impact of extreme distance (Underhill, Goldstein et al. 2006).

Barton (2002) notes that a lot of thinking about quality and throughput volumes is related to American studies from the 1970s and 1980s and the evidence from the surgical literature on survival and tumour control, which supports critical mass. Treatment throughput cannot be assessed in isolation without any consideration for treatment quality, treatment outcomes and patient or staff satisfaction (Delaney, Shafiq et al. 2005).

Professor Lester Peters from the Peter MacCallum Cancer Centre in Melbourne has reported on a large international trial designed to investigate a new drug to see if when added to radiotherapy it could improve the survival of patients with advanced head and neck cancer⁷. The trial was designed to detect a possible 10 per cent improvement in survival as a result of adding the drug. A key finding was that the quality of radiotherapy was much more significant than the presence or absence of the new drug. The difference in survival between patients who got acceptable or

7 Source: <http://www.abc.net.au/am/content/2010/s2960796.htm> accessed 18 October 2010.

unacceptable radiotherapy was 20 per cent at two years, it was 70 per cent survival in those who got good radiotherapy and only 50 per cent in those who got unsatisfactory radiotherapy. He comments:

'However, I think the logical extrapolation of our results in the context of Australia is that as more and more regional cancer centres are opened up there are certain types of complex cancers that are probably still best treated in the major facilities. The difficulty is to reconcile the convenience of treatment in the regions with the impossibility of maintaining sub-specialty expertise in every small facility.'

4 Synthesis of key messages from the literature for NSW Health

4.1 The evidence

This section aims to summarise the main findings from the literature in a series of bullet points to assist the reader to form their own conclusions on the basis of the evidence presented.

The evidence from this targeted literature review is equivocal. Planning to achieve economies of scale through the most cost effective machine configuration needs to be considered in light of not only the impact on access to services but also issues such as costs, machine capacity, workload and throughput considerations, workforce availability, geographic access, quality and safety.

Multiple factors will influence decision-making for this service planning issue. This literature review provides another ingredient for the 'melting pot', it will be supplemented by new and emerging evidence, advances in best practice, the advice of clinical and technical experts, patient preferences and undoubtedly available public funds.

In summary the major findings from the literature are:

Costs and Economics

- Radiotherapy capacity to respond to increasing cancer numbers requires long term planning and investment in education and infrastructure.^{10, 56, 80}
- Radiotherapy requires a large 'up-front' capital investment with these costs amortised over the ten to twelve-year machine life.^{9, 46, 51, 57, 59}
- Radiotherapy is a cost-effective treatment option.^{23, 57}
- Radiotherapy continues to evolve with new technology and techniques widening the indications and options for therapeutic treatment and palliative care.^{10, 57, 75}
- Smaller facilities are seen to have an impact on the cost and cost-effectiveness of radiotherapy services.^{9, 29, 79}
- A simulation study from Ontario, Canada concluded that the cost of radiotherapy in a facility treating less than 1600 patients per year starts to rise. At 400 patients per year, a course costs approximately 50% more than at 1600 patients per annum. The significant increase in cost below 1600 patients per year comes from underutilisation of ancillary equipment. The slow decrease in cost above 1600 patients results from the sharing of the cost of supervisory positions over a greater number of patients. On the basis of this model the authors found no significant economies of scale for facilities with more than four fully utilised treatment units.²⁹
- The Evaluation of the National Single Machine Unit (SMU) Radiotherapy Trial conducted in Victoria commenced in 2003 included information on the costs and economics of SMUs. The additional costs of providing treatment at the SMUs compared to the hubs ranged from \$0.2 to \$1.3 million per annum. This reported wide variation is derived from a small sample size.⁷⁹
- Costs per course at the regional centre of Ballarat were between 19-36 per cent higher than the metropolitan hub, at the Austin. The higher uptake of IMRT at this centre may have been a factor. Activity levels at all centres most significantly impacted on cost per course.⁷⁹
- A comparative analysis of a Commonwealth-initiative regional radiation oncology facility in Toowoomba with a Queensland health facility found that the average Medicare cost per treatment course was similar in both centres (\$5000 per course). Total costs of an average treatment including patient, State and Commonwealth costs, showed a 30% difference in costing favouring Toowoomba. Most of this difference is reflected in the staffing levels.⁶¹

- The cost of radiotherapy is mainly determined by the length of the treatment (number of fractions) and by the daily treatment time. This means that departments should be of sufficient size to optimise cost-effectiveness.¹⁰
- Even in this era of very sophisticated and costly radiotherapy equipment, personnel costs remain the most important cost component of a radiotherapy department, consuming about twice the budget of equipment (in the magnitude of 52% versus 28%).^{10, 53}
- Costing models should be developed at a supra-institutional, international level. Such a costing model would yield the necessary cost data to perform economic evaluations of new treatment strategies and potentially analyses relating to scale.^{10, 41}
- Planning and service development strategies should not focus only on economies of scale, there are references in the literature to 'economies of scope' which can be realised because of the complementarity of radiotherapy as a treatment modality with other treatment modalities, this in turn generates a demand for a certain level of hospital infrastructure.^{60, 70}

Machine Capacity

- Planning parameters, such as population catchments, cancer incidence, evidence based treatment guidelines and machine throughput are considered when determining linear accelerator requirements.^{9, 70, 80}
- The utilisation of equipment offers potential to achieve economies of scale.^{29, 53, 60}
- Linear accelerator throughput is quantified as the number of treatment courses per year. This will vary with a multitude of factors including the complexity of delivered treatments, number of fields, number of dose fractions, extent of quality assurance procedures and the efficiency of equipment and staff, including processes, workflow and technological developments.^{9, 10}
- Several studies have shown that maximum acceptable percentage utilisations are between 85-95% depending on the number of matched linacs and on the maximum acceptable delay.⁷⁴
- Linear accelerators cannot be run at average utilisations in excess of 90% without causing delays to patients' treatments as a result of random fluctuations in demand.⁷⁴ This only in a no waiting list scenario. Where a waiting list exists, this does not apply.
- The level of excess capacity required to avoid delays depends on whether the machine is run as a single machine or part of a matched pair, additional considerations include the ability to move patients between machines.⁷⁴
- Modelling completed in the UK demonstrates that for a given level of demand, capacity needs to be about 10% greater to avoid queues, (a key assumption being that 86% of patients are able to start radiotherapy within a week of completing the treatment planning process).^{18, 74}
- Studies have shown a high correlation between equipment capacity and degree of utilisation. A high correlation was also found between input of manpower and output of fractions in Swedish departments of radiotherapy.⁵³ This was also achieved through the Victorian SMU trial where utilisation/machine was the highest in the country for Ballarat & Bendigo.^{14, 69, 79}
- Newer machines with more recent technological enhancements have been shown to generate higher throughput.²²
- Satellite centres may start as a single machine unit (SMU) but should be developed with two bunkers to facilitate expansion to a two machine unit.^{9, 15, 27, 31, 47, 61, 62, 79}
- Internationally it is more common for new linacs to be located within existing hub and spoke centres.^{11, 12}
- There are very few examples in the literature of single machine units; the most common number of linear accelerators in a comprehensive cancer centre is customarily between two and four linacs.^{9, 30, 40, 52, 56, 62, 67}
- There is one Belgian study in the literature that reports that a lower threshold for department size was found to be around 1000 patients treated annually, this is primarily because of the impact of economies of scale in the calculation of average and specific radiotherapy costs.

Due to the indivisibility of some resources, large-scale departments can treat their patients at a lower cost per case: if a simulator, for example, can serve up to three linacs, then the unit cost for the simulator declines as the volume increases.^{10, 41}

- There is no definitive evidence in the academic literature, relating to the maximum number of linacs within one treatment centre. The maximum number of linacs found in the academic literature was eight in a major Swedish treatment centre but this data was from 2000. A review of the web identified 11 linacs at The Beatson West of Scotland Cancer Centre in Glasgow. The largest number of linacs found in one centre was at the Odette Cancer Centre (13 linacs) and the Princess Margaret Hospital (17 linacs) both within the Toronto Central Region of Canada.^{53, 67, 82}
- The National Radiotherapy Advisory Group of the United Kingdom provides the view, based on the 'experience of those working in large centres', that a maximum of six to eight linacs is optimal. One linac only services are not supported given their potential impact on patient treatment should the machine be unexpectedly out of action. Minimum size for providing 'whole' service (simulation, planning and treatment) should be three to four linacs, still with links to a larger centre for specialised treatments. Within the UK context, their planning recommendation is four to eight linacs per department.⁵²
- In Australia no centre is planned to have more than eight linacs in one location.^{56, 62, 80}
- In Australia the largest numbers of bunkers are at the Peter MacCallum facility, (currently six, with expansion to eight by 2014/15). This may be matched by developments at Royal Brisbane and Women's Hospital with plans to expand over time to seven to eight linear accelerators.^{62, 80}
- The majority of public units in Australia have between two to four linacs. In a 2009 survey, almost half of all facilities (48.9%) had only two linear accelerators, and another 11 facilities (24.4%) had just three linacs in service.^{40, 56, 62, 80}

Optimal workloads and throughput targets

- A key factor to consider in the siting of linacs is ensuring that departments have a sufficient workload to make them viable to run. The importance of justifying that additional treatment capacity is warranted has also been recognised in the Australian context.⁹
- There are published benchmarks for accelerator throughput, these benchmarks are most often used to estimate the number of linear accelerators per million people required to facilitate appropriate radiotherapy utilisation rates in each country.^{10, 19, 40, 53, 78}
- The Basic Treatment Equivalent (BTE) developed in Australia, remains the best measure of linear accelerator throughput.²¹
- Variations in radiotherapy provision affect the utilisation of this treatment modality. In several EU countries inadequate provision of radiotherapy resulted in long waiting times and poorer treatment outcomes.¹⁰
- The Swedish SBU study reported actual average annual throughput per unit in Sweden in 2001 was 338 treatment courses with a variation among centres ranging from 248 to 442. There was a high correlation between the number of linear accelerators and the volume of fractions of radiotherapy, which suggests the occurrence of certain economies of scale in Swedish external radiotherapy.^{10, 53}
- From the Australian ROJIG parameters, the maximum capacity for a linear accelerator is 414 courses of treatment per year, consisting of 331 new patients and 83 patients (25% of 331) being re-treated. These parameters remain unchanged since their issue in 2003.⁶³
- Planning for optimal machine configuration should consider unplanned downtime that increases with machine age and replacement of old machines which can take up to approximately four months. It is advisable to factor the workload generated from non-notifiable diseases (about 10% of treatments) and the complexity of treatment required for certain cancers.⁴⁶

- Changes in work practices offer the possibility of treating more patients for a given amount of resources or time and may be an important aid to improving patient access.^{9, 13}
- Technological and clinical advances resulting in increasingly complex, multi-field treatments are becoming more common in the clinical environment, for example, intensity modulated radiotherapy (IMRT), intra-operative radiotherapy (IORT) and high dose rate (HDR) brachytherapy.^{17, 43}

Workforce availability and engagement

- The constraints generated by limitations in the availability of an appropriately trained workforce is frequently mentioned in both the academic and practice literature.^{9, 8, 44, 45, 46, 61, 72}
- Larger centres may have economies of scale, particularly in relation to staffing.²⁵
- Developing radiation oncology services in areas distant to major population centres is often not possible for reasons such as an inability to attract sufficient numbers of specialist staff, insufficient caseload to justify a stand-alone service, or insufficient support or expertise at the local hospital to manage and operate such a specialist service.²⁵
- The Victorian SMU evaluation found that SMU staff were happy to work in smaller, team-oriented and less bureaucratic environments than hubs; however professional development was an area that required improvement.⁷⁹
- This hub and spoke or 'networked' service model provides the opportunity for cross-appointment of staff, leave cover and peer review.⁷
- Advanced or extended scope practice in radiation therapy is an accepted role in the UK and Canada. These positions allow radiation therapists to specialise in technical and holistic aspects of patient management.²

Geographic access

- Improvements in access and equity to radiotherapy services are required in both Australia and New Zealand in order to achieve the recommended 52.3% treatment rate.⁴⁶
- Distance and waiting times have been found to be a significant disincentive to having prolonged radiation therapy.^{1, 6, 11, 15, 33, 39, 42, 68,}
- Patients who lived further from regional cancer centres are less likely to receive radiation. This finding has been mirrored for differing cancers in other countries.^{9, 20, 24, 34, 58}
- Patients trying to access radiotherapy may experience psychological trauma, financial outlays and extended travel times.^{12, 36, 46}
- Specific themes identified in two Australian papers were: being away from loved ones, maintaining responsibilities whilst undergoing treatment, emotional stress, burden on significant others, choice about radiotherapy as a treatment, travel and accommodation, and financial burden.^{36, 42}
- In the UK patient surveys have indicated that there is substantial reluctance to accept daily travelling times of longer than 45 minutes each way. A drive time analysis for radiotherapy has shown that 87% of the population already live within 45 minutes of a radiotherapy centre. In England, the situation is very different to Australia, with 94% of the English population living within 50 km from their nearest Radiotherapy Centre.⁵⁰
- An economic evaluation (based on Canadian data), found that from a societal cost perspective only, that outreach radiotherapy (central comprehensive facility and satellite) is the economically superior model for separations between 30km and 170km. Beyond 170 km, a fully decentralised service would be warranted if the only consideration were societal economic advantage.²⁸
- The move towards a satellite or outreach model has been identified in Norway, Sweden, Canada and the UK, as one way of improving geographic access.¹²

- This is a growing trend in Australia where the dependence on large cancer centres such as the Queensland Radium Institute and the Peter MacCallum Cancer Institute in Melbourne are giving way to more city centres and satellite centres, particularly in country locations.⁴⁷
- Rural access has improved with new departments in Bendigo, Ballarat, Traralgon, Port Macquarie, Coffs Harbour and Toowoomba plus others planned for Orange, Lismore, Gold Coast, Cairns, Darwin and Bunbury.^{46, 56, 62, 80}
- The NSW Department of Health (2010) 'Radiotherapy Services in NSW Strategic Plan to 2016' details the NSW locations funded by both NSW and under the Commonwealth Government Health and Hospital Fund Regional Cancer Centre Initiative announced in April 2010. In summary, this has led to the funding of two bunker, single machine units in Tamworth and Nowra and a two linear accelerator unit in Gosford. A second linear accelerator has been funded for both Lismore and Port Macquarie and a third linear accelerator for Wollongong.⁵⁶
- The academic and practice literature shows the efforts of governments to balance better access to radiotherapy services through addressing the location of radiotherapy services, support for travel costs and patient accommodation.^{12, 42, 46, 50, 51, 58, 61}
- Whilst schemes exist to support patient travel and accommodation these are unable to keep pace with demand and the costs and impost of travel and costs of accommodation can be real barriers to radiotherapy access.⁴⁷
- Single machine units are a valid treatment option and capable of delivering care at an equivalent standard to that of larger comprehensive cancer centres. They improve access for patients and reduce transport and accommodation costs.^{14, 25, 27, 47, 69}
- Risks of a SMU include '...the challenges of clinical support, ease of referrals for complex or less common treatments, ...research, the inability to specialise, staff back-up arrangements, and the heavy impact in the event of a problem with the machine.'¹²
- The view most commonly expressed in the literature is that satellite centres may start as a single machine unit (SMU) but there are usually plans to expand to a two machine unit. There needs to be a formal link to a larger centre for clinical support, data collection, research and access to expertise for referral of less common cancers, often in a hub and spoke type arrangement.^{9, 15, 27, 31, 47, 61, 62, 79}
- As a model across Australia, the distance between hubs and spokes may limit the ability of SMUs to be effectively operated, serviced and maintained with integration from a hub centre. Within Victoria, no spoke was more than 2.5 hours by road from the hub, enabling travel within a single day between the hub and spoke.⁷⁹
- Cancer Council NSW recommends that preferred model for all centres is at least two machines, with single machine units only established where there are close geographic and service ties to another radiotherapy facility.¹²
- In NSW networking models are in place between Comprehensive Cancer Centres and satellites, for example, Westmead is linked with Nepean; Port Macquarie is linked with Coffs Harbour and Liverpool is linked with Campbelltown. New departments proposed for regional areas in NSW will be linked in a similar manner e.g. Illawarra and Shoalhaven.^{47, 56}

Quality and Safety

- Radiotherapy has a long history of quality assurance with an appropriate focus on radiation safety.^{17, 38, 75}
- Within the limits of our search of the literature we did not find any evidence of safety issues that are explicitly related to economies of scale and linac machine configurations.^{69, 79}
- The evaluation of the National Single Machine Unit Radiotherapy Trial previously referred to in Victoria, found the number of incidents per 100 courses reported at the regional centres of Bendigo and Ballarat were comparable with, or lower than, their hub services over the four years 2003 – 2006.⁷⁹

- There is significant variation in the ways in which centres manage their quality assurance and quality improvement activities.^{13, 40}
- The importance of a persistent safety conscious culture within radiotherapy departments is identified.⁷⁶
- As radiotherapy techniques become more complex it is difficult to rely on a manual checking process to detect and minimise errors. A rigorous ongoing quality assurance process is essential.¹⁷
- Treatment throughput cannot be assessed in isolation without any consideration for treatment quality, treatment outcomes and patient or staff satisfaction.^{7, 22}
- Advances in remote monitoring systems now offer opportunities to maintain technical quality while enhancing patient access. Telemedicine is another model that has proven beneficial in reducing the impact of extreme distance.^{64, 77}
- As more and more regional cancer centres are opened up there are certain types of complex cancers that are probably best treated in the major facilities. The difficulty is to reconcile the convenience of treatment in the regions with the impossibility of maintaining sub-specialty expertise in every small facility.^{64, 77}

4.2 Concluding remarks

The basic principles for cancer services, regardless of whether they are public or private have previously been set out by the 'Expert Advisory Group on Cancer to the Chief Medical Officers of England and Wales' (1995). They are just as relevant to the planning of comprehensive cancer services today:

- High-quality care, available to all, as close to home as possible
- Public and profession education to assist in the early recognition of cancer
- Clear information to assist patients and their families about the options for treatment
- Patient-centred services taking into account the patient's views and preferences
- Good communication between different service providers at all stages
- Cancer registration and careful monitoring of treatment and outcomes.

NSW Health should continue to monitor developments in radiotherapy, particularly if they impact upon costs, machine capacity, workload and throughput considerations, workforce availability, geographic access, quality and safety.

Determining the optimal machine configuration for centres must balance many competing factors - ultimately the quality of clinical outcomes is perhaps one of the most important criteria on which to base our judgement.

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