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Four considerations before embarking on a carbon therapy center

By Erik Mollo-Christensen

Carbon, otherwise known as heavy ion or hadron, therapy is the next generation of particle therapy in the U.S. Originally developed in the U.S. in the 1970s, carbon therapy technology offers higher energy treatment and effectiveness against some tumor types and conditions, as well as shorter treatment courses with fewer fractions and patient visits than proton therapy.

As part of the continuing development and improvements to cancer treatment, it's no surprise that healthcare providers are seeking to refine and advance treatment methods in radiation oncology. There are more than 70 operating particle therapy centers worldwide, including 12 international carbon facilities. Another 40 proton and 5 carbon projects are under construction. In addition to these facilities, several premier domestic institutions are considering carbon facilities to bring heavy ion treatment to the U.S.

The primary characteristic and benefit of carbon therapy results from the greater mass of the particles. Proton therapy uses hydrogen atoms, whereas particles from heavier elements (carbon, helium) have more mass and therefore more kinetic energy. This results in greater damage to cancer cells, and – considering the tighter deposition pattern and smaller margins – reduced harm to healthy cells. This also accumulates the prescribed doses in fewer fractions (typically 10-12 for carbon) and decreases the length of the treatment course for the patient.

While carbon therapy presents great opportunities in the fight against cancer, the advanced technology and equipment brings a new level of consideration in site and facility planning for owners contemplating a project. In Stantec's decades of focused practice guiding planning and design of particle therapy facilities, we have learned that there are several factors healthcare providers must consider when implementing new treatment technology like carbon therapy to ensure the success of a facility.

Generally, there are four key factors to consider prior to exploring the feasibility of a carbon therapy facility. They include:

- Equipment characteristics
- Planning, architecture, and facility design
- Engineering design considerations
- Cost and construction

Equipment characteristics

Before considering the design of a carbon therapy facility, it's important to understand equipment components and operations, along with the resulting impacts on project planning and design.

Many existing carbon centers were developed from institutional research accelerator equipment, but commercial systems are now being offered by manufacturers such as Hitachi and Toshiba, while others are developing integrated systems. Such systems are capable of using both protons and heavy ions, and can accommodate a combination of proton and carbon treatment rooms.

The existing institutional and commercial carbon systems use synchrotron accelerators (a carbon cyclotron is under development, as well). The typical energies required for heavy ions are in the range of 400-450 MeV, significantly greater than the 230-330 MeV for protons, and necessitate a synchrotron diameter of 65 to 80 feet due to the greater particle mass. Accelerators using multiple ions also require multiple injectors (typically linear accelerators) located inside the ring, in an adjacent room, or at an upper level.

Currently, most carbon facilities provide fixed beam treatment only, but the Heidelberg Ion Treatment Center in Germany includes the first custom-built gantry – weighing 600 tons. More recently, a superconducting cryogenic gantry has been developed in Japan which is smaller and lighter (but still larger than a proton gantry).

Horizontal and vertical, or inclined fixed beams, have been used in most existing carbon facilities. It's important to consider the fact that the greater particle mass of carbon requires larger bending radii. Compared to proton therapy, vertical beam lines are much higher, often requiring three- to four-story shielded upper levels.

Impacts to planning, architecture, and facility design

The design and planning implications of large carbon equipment are considerable. For one, the shielded concrete bunkers and needed space for equipment are significantly larger. Although the basic clinical diagram and patient flow is similar to that of proton, the necessary technical space requires much more area in plan, as well as height in section. This also means that existing proton centers cannot be easily modified for carbon equipment; separate or adjacent carbon facilities must be built.

Some of the major variations required for carbon therapy, as compared to proton, include:

- Synchrotron room is twice as wide and long, but similar height;
- Beam line at main level is similar, but vertical fixed beams require an upper beam line of up to four stories high;
- Gantry bunkers are much larger and higher/deeper;
- Fixed beam rooms are similar in plan, but require an upper level for vertical beams;
- Power supply rooms are much larger to accommodate greater quantity of power and control cabinets.

The shorter treatment course (and cost), and the opportunity to continuously improve cancer treatment are strong reasons to move forward.

In addition to the increased space needed for carbon therapy equipment, shielding requirements will also influence project design and planning time. Shielding for carbon follows the same general principles as that for neutron shielding, where concrete is typically the most cost- and space-effective material. At this stage, options for alternate high-density shielding materials are limited since there is not a great deal of data available.

Engineering design considerations

The major difference in carbon systems from that of proton is the requirement for almost twice the electrical power (up from typical power needs of up to 6 MW). This also translates into greater process cooling requirements, as higher power consumption increases demand for process cooling water and, like synchrotron-based proton systems, requirements for isolation/conditioning of harmonic issues.

Additionally, the accelerator, beam line and gantry magnets, and power/control cabinets all accumulate additional flow and cooling capacity for building systems, which create an even greater challenge to typical campus central utility systems capacity.

These components, in turn, affect first and operating costs. From a facility planning and management perspective, it's also important to note that limited available data from active carbon facilities impacts the ability to predict actual operating loads and optimize electrical service capacity.

Cost and schedule

There are several aspects to consider when estimating the cost of a carbon facility. The larger size and power requirements of carbon systems carry higher costs than proton equipment. The earlier stage of development of commercial carbon systems also means there is less established precedent for the full cost of furnishing and installing a system, and less certainty about final total project costs.

Building construction costs are also more challenging to predict and manage. Although the clinic and non-shielded portions of carbon centers are similar to proton and other medical facilities, there is limited data on carbon center construction, making estimating from benchmarks very challenging. The greater height and volume of the shielded concrete bunkers make proton construction costs per square foot an unreliable predictor for carbon costs.

Other factors influencing cost include:

- Heavier bunker and gantry point loads require more foundation support;
- Larger equipment utility loads require more power and cooling;
- Longer construction time adds to contractor management costs.

These considerations will also play a role in construction time. The larger/heavier bunkers will require more time for construction. And depending on the number of treatment rooms, the time from start of construction to when the facility is ready to receive the equipment will be greater than the 12-16 months typically accomplished in a proton facility.

In addition to the construction factors, design for evolving technology and equipment may require more time to finalize interface documentation and resulting building design. The clinical variations in treatment for carbon therapy may also require more planning and design time to address different patient volumes and case mix, not to mention the uncertainties of FDA approval that may require more equipment design resolution and building design time.

Those pursuing a new carbon facility can also expect greater shielding analysis time since there is less data available from operating facilities and a smaller cohort of experienced heavy ion facility physicists. And the absence of extensive regulatory shielding experience may require more time for review and approvals.

To mitigate such challenges, an experienced architecture and engineering team provides high value and lower risk for owners. As with any emerging method, partnering with a team at the leading edge of new applications will help streamline planning, anticipate hurdles, and address issues proactively.

The value of carbon

The current state of carbon therapy is similar to the early days of proton center projects: the commercial treatment systems are relatively new, the clinical function and work flow variations are evolving, the cost and project schedules are higher, and the systems are not FDA approved yet. So why pursue carbon?

The clinical benefits of treating previously untreatable or difficult cancers, the shorter treatment course (and cost), and the opportunity to continuously improve cancer treatment are all strong reasons to move forward.

About the Author: Erik Mollo-Christensen, AIA, is a senior associate at Stantec, a leading global design firm recognized for its Particle Therapy Center of Excellence. For more than 25 years, Mollo-Christensen has specialized in planning and designing particle therapy facilities across the globe.

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