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March 2019

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[illegible]. 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

[illegible]

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.

- Synchrotron room is twice as wide and long, but similar height;
- Beam line at main level is similar, but vertical xed 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.

In addition to the increased space needed for carbon therapy equipment, shielding re-