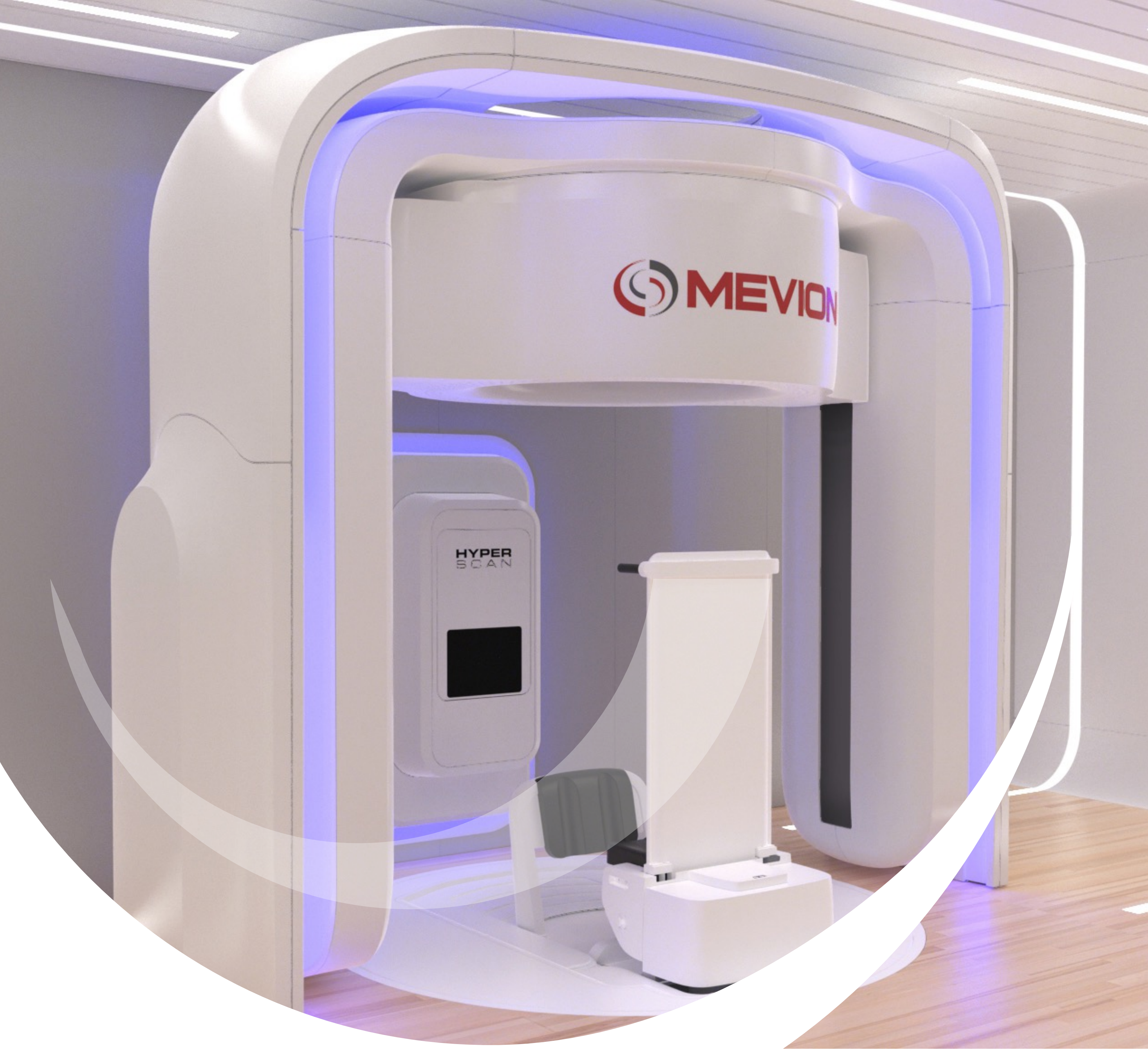

Re-Imagine Proton Therapy:

A Flexible LINAC Vault Design to Accommodate Proton Therapy

Abstract

The increasing adoption of proton therapy in cancer treatment underscores the need for adaptable radiation therapy facilities. This paper explores the feasibility of designing a new linear accelerator (LINAC) vault with future proton therapy integration in mind, specifically focusing on the MEVION S250-FIT system. By analyzing the shared requirements and key differences between LINAC and proton therapy systems, we identify the necessary modifications to vault infrastructure, including shielding, ventilation, and space considerations. We also highlight the potential benefits of this approach, such as cost-effectiveness, time efficiency, and scalability. This proactive strategy allows healthcare facilities to embrace the future of cancer care by seamlessly transitioning to proton therapy when the time is right, ensuring access to cutting-edge treatment options for their patients.

Introduction

Proton therapy has emerged as a transformative force in cancer treatment, offering unparalleled precision and minimizing damage to surrounding healthy tissues compared to traditional radiation therapy. This targeted approach has proven particularly beneficial for tumors located near critical organs or in pediatric patients, where minimizing long-term side effects is paramount. However, the widespread adoption of proton therapy has been historically constrained by the substantial capital investment required to build and maintain dedicated proton therapy centers. These facilities typically house large, complex equipment, including particle accelerators and beam delivery systems, necessitating specialized infrastructure and expansive space.

The development of ultra-compact proton therapy systems, exemplified by the MEVION S250-FIT, represents a paradigm shift in addressing these challenges. By integrating cutting-edge technologies and optimizing system design, these compact systems offer comparable treatment capabilities to traditional centers while significantly reducing the footprint and infrastructure requirements. The MEVION S250-FIT, in particular, is engineered to fit within the confines of existing LINAC vaults, eliminating the need for costly new construction and streamlining the integration of proton therapy into existing healthcare facilities.

This paradigm shift not only enhances the financial viability of proton therapy but also accelerates its accessibility to a broader patient population. A 2022 article found that from 2004 to 2018, the percentage of patients receiving proton therapy rose from 0.4% to 1.2% (Nogueira, 2022) of the US radiation therapy market. In 2023 a leading cancer institution publish that the predicted adoption of proton therapy could become 15% (Yan, Susu et al, 2023, pg. 3) of the overall domestic radiation treatments. This is a conservative estimate as the same paper finds 15-50% (Yan, Susu et al, 2023, pg. 6) of all cancer patients receiving radiation could benefit from protons. For institutions to prepare for this forecast increase, they should focus on reducing the cost and accelerate the availability of proton therapy to their patients.

*Figure 1: Stanford Health Care **MEVION S250-FIT** treatment room - Image by Stantec Architecture inc*

The MEVION S250-FIT Proton Therapy System is not yet available for clinical use.

Shared Requirements Between

Mevion S250-FIT and A Standard LINAC

While the specific technical specifications and equipment differ between MEVION S250-FIT and traditional linear accelerators (LINACs), they share fundamental requirements for safe and efficient operation.

Radiation Shielding

Both systems necessitate a highly shielded vault or bunker to protect personnel, patients, and the public from ionizing radiation exposure. Adjacent spaces within and external to the clinic drive the siting, orientation and shielding of the walls and ceiling of the vault.

Key Elements Include:

01 **Primary barriers:**

Thick, dense materials (typically concrete, lead or steel) to attenuate the primary radiation beam.

02 **Secondary barriers:**

Shielding to protect areas exposed to scattered radiation from sources such as the patient and the beam line elements.

03 **Door shielding:**

Heavy doors of composite construction, typically involving steel structure, regular or HD block cores with thicknesses varying depending on primary beam energy direction with respect to the vault entry.

04 **Shielding calculations:**

Precise calculations based on beam energy, , workload, , and occupancy to determine appropriate shielding thickness.

HVAC System

A well-designed HVAC system is crucial for maintaining air quality and safety in both LINAC and MEVION S250-FIT vaults. Essential components include:

01 **Negative pressure:**

Maintaining a lower air pressure in the vault compared to adjacent areas to prevent the escape of contaminants.

02 **HEPA filtration:**

High-efficiency particulate air filters to remove airborne contaminants.

03 **Ventilation rates:**

Adequate airflow to ensure proper exchange of air between the vault and the outside environment.

04 **Temperature and humidity control:**

Maintaining optimal conditions for equipment and patient comfort.

Support Spaces

Auxiliary spaces are required for the operation of both systems:

01 **Control room:**

Dedicated area where clinical staff and therapists control the machine, , monitor patients during treatment and interface with hospital IT infrastructure.

02 **Ancillary Equipment room:**

To house all supporting equipment for either the LINAC or the proton system. This room should be flexible space as the proton equipment requires more sq/ft than is typical for LINAC's.

03 **Storage areas:**

For patient setup devices, , treatment accessories, , and potentially radioactive materials.

04 **Staff areas:**

Locker rooms, break rooms, and offices for treatment staff.

While these core elements are shared between MEVION S250-FIT and standard LINACs, , specific requirements and design considerations may vary due to differences in equipment size, , beam characteristics, and workflow.

Conversion **Feasibility**

Converting a traditional linear accelerator (LINAC) vault into a proton therapy facility presents both challenges and opportunities. While the fundamental components of a radiation therapy vault—shielding, ventilation, and support spaces—are shared between the two modalities, significant modifications are often necessary to accommodate the unique requirements of proton therapy.

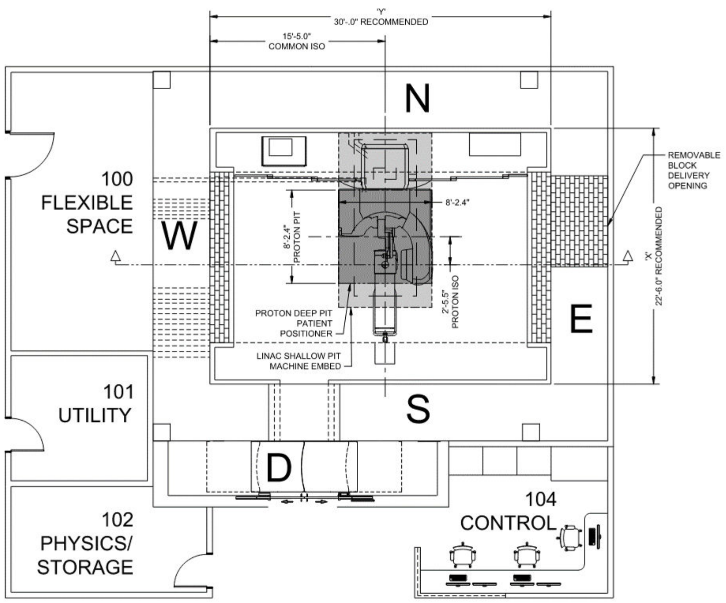

Figure 2 - Floor Plan – Room with LINAC

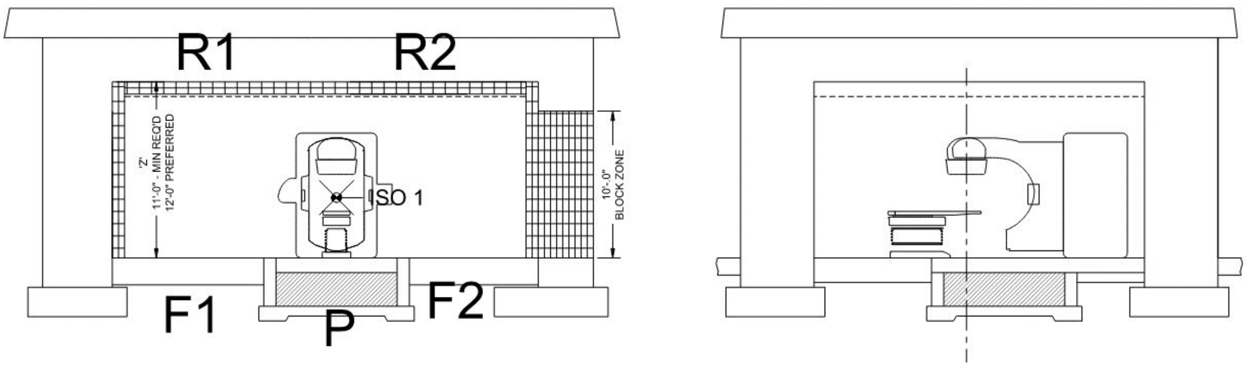

Figure 3 – Sections - Room with LINAC

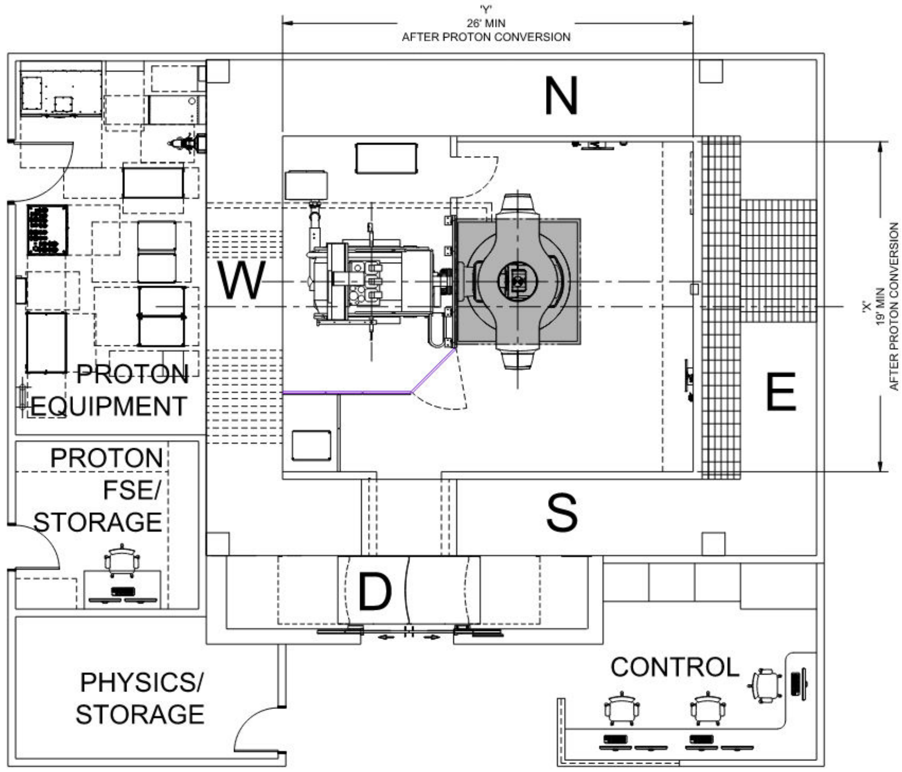

Figure 4 - Floor Plan – Room with Compact Proton

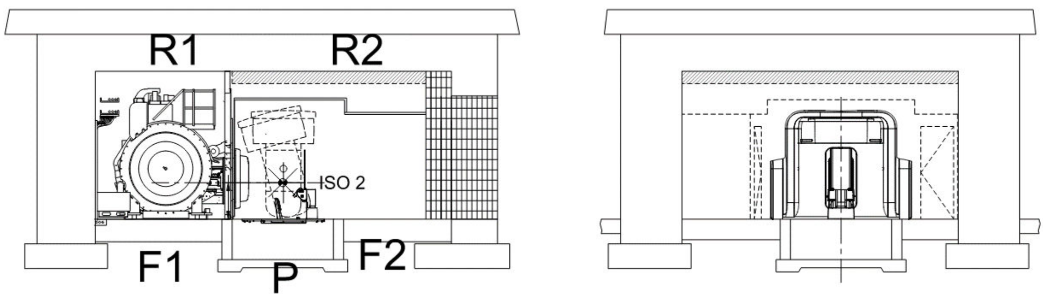

Figure 5 - Sections - Room with Proton

Challenges

Space Constraints

Proton therapy equipment, particularly the cyclotron, can be larger and require more space than LINAC systems in the treatment area. Vault dimensions need to be carefully considered to ensure an efficient clinical space when converting from a LINAC to S250-FIT treatment system. As both systems require a slab depression / machine pit, aligning the system ISO within the room allows for the differences in dimensions of the pit to be accounted for.

- **Table 1** provides the minimum clear dimensions from inside of shielding to inside of shielding for a flexible vault. For comparison, values for a not flexible construction are given as well, LINAC only support.

Table 1 - Vault Dimensions

Vault Dimension	LINAC Config	FIT Config
Vault Length 'Y'	26'-0"	26'-0"
Vault Width 'X'	22'-6"	20'-6"
Vault Height 'Z'	12'-0"	12'-0"
Typical LINAC (not flexible)		
Length 'Y'	20'-0"	N/A
Width 'X'	21'-0"	N/A
Height 'Z'	11'-0" (recommended)	N/A
Clinical Dimension		
System ISO Z Height	1.29m (4'-3")	0.9m (2'-11.4")
System ISO 'Y' from W	15'-5"	15'-5"
System ISO 'X' from S	10'-6"	12'-11"
Beam Direction	360-degree gantry	Fixed, towards wall E

- **Table 2** provides the slab depression / machine pit dimensions for a flexible vault

Table 2 - Machine PIT Dimensions

Dimension	LINAC Config	FIT Config
PIT 'Y'	1.7m (5'-7")	2.5m (8'-3")
PIT 'X'	4.35m (14'-3")	2.5m (8'-3")
PIT 'Z'	0.3m (1'-0")	1.0m (3'-3")

Delivery/Installation

A typical LINAC replacement can be done over the course of a few weeks and requires a 4’ x 7’ entrance door for equipment removal and delivery. While many of the components in a S250-FIT can be delivered through this same opening, the cyclotron requires an opening large enough to support its size, weight and rigging equipment.

- **Table 3** provides the minimum clear dimensions for various rigging and installation paths

Table 3 - Delivery Openings

Dimension	LINAC Config	FIT Config
Wall E – Option 1	N/A	8’ Wide x 10’ Tall
Wall N – Option 2	N/A	8’ Wide x 10’ Tall
Roof R1	N/A	6’ Wide x 10’ Long
Door 1	4’ Wide x 7’ Tall	4’ Wide x 7’ Tall
Largest Components		
Primary beam and gantry	11’-6” x 4’-0” x 6’-6” (<20, 000 lbs)	9’-0” x 5’-0” x 9’-4” (70, 000 lbs)
Broken down into smaller sections	6’-6” x 3’-8” x 6’-6” (4, 800 lbs)	N/A

Shielding Requirements

While neutron production is a characteristic of both devices, neutrons from proton interactions have higher energies. Denser and thicker bulk shielding will be needed in some locations. However, due to the fixed beam nature of the S250-FIT, there are optimization strategies to employee during initial design of a flexible vault.

- **Table 4** provides example dimensions and makeup of primary shielding, (note all dimensions are approx. and require certified shielding design taking into account adjacent occupancies and patient workload).
  The design should utilize modular shielding materials that can be re-configured during a proton conversion.

Table 4 - Shielding

Vault Location	LINAC Config	FIT Config
Wall - N	Not primary, 5’ concrete	Secondary scatter, 5’ concrete and modular HD block as needed
Wall - E	Primary, 6’ concrete with modular HD block as needed	Primary direction, 6’ concrete with modular HD block as needed
Wall – S	Not primary, 5’ concrete w/ door	Secondary scatter, 5’ concrete and modular HD block as needed
Wall – W	Primary, 6’ concrete with modular HD block as needed	Secondary scatter, 5’ concrete
Roof – R1	Primary, 5’ concrete with modular HD block as needed	Secondary scatter, 5’ concrete w/ HD block or steel plate as needed
Roof – R2	Primary, 5’ concrete with modular HD block as needed	Secondary scatter, 5’ concrete w/ HD block or steel plate as needed
Door – D	Direct shield, 2-3’ for LINAC	Direct shield, 5’ regular or HD block fill as needed

Ventilation, Heat Load & Air Quality

Proton therapy may introduce new contaminants or require different ventilation rates. Ensuring proper air exchange and filtration is essential to maintain a safe environment for patients and staff. Designing an ACH for the entire treatment room that aligns with the needs of a future proton upgrade, especially for the small amount of liquid helium in the superconducting magnet, will greatly simplify the conversion.

- The design of all penetrations through bulk shielding needs to be closely designed with shielding from radiation leakage. Where possible, penetrations should occur with no direct line of sight to ISO and be behind the primary beam direction. For proton systems, a mazed entry can simplify some of these shielding concerns.

- **Table 5** provides basic requirements for HVAC heat loads, process water heat loads and ventilation rates.
  Note these are peak rates based on treatment state

Table 5 - HVAC and Ventilation

Room HVAC Load	LINAC Config	FIT Config
Treatment Room	~8 kW	8.0 kW
Accelerator Room	N/A	12 kW
Equipment Room	~6 kW	21.5 kW
Control Console	~2 kW	~2 kW
Room ACH		
Treatment Room	4-6 typical	4-6 typical
Accelerator Room (quench)	N/A	Increase 10+ ACH during magnet quench, no direct vent required

Infrastructure Modifications

Designing the electrical and mechanical systems to accommodate the increased power demands of proton therapy equipment is crucial for a flexible vault design. Additionally, modifications to mechanical systems, such as facility chilled water and HVAC balancing, may be required to support the new technology.

- **Table 6** provides basic power and mechanical system loads.

Table 6 - Power and Mechanical

Room HVAC Load	LINAC Config	FIT Config
System electrical	480v, 80A, single feed	480v, 300A, single feed
UPS	N/A	200 kW, full system backup
Control console	208v, 20A	(3) 110v, 20A
Process Water Load		
Treatment Room	12.5kW ready, 25 kW beam on	N/A
Accelerator Room	N/A	N/A
Equipment Room	N/A	40kW magnet on, 80kW peak during beam on
Emergency City Water	Yes, <5 gpm	Yes, 8 gpm with dedicated drain

Advantages Of
Proactive Design

Adopting a proactive approach to design a LINAC vault with future proton therapy conversion in mind yields several significant advantages:

Financial Prudence

By leveraging existing infrastructure and strategically planning for future needs, healthcare facilities can significantly reduce construction costs compared to building a dedicated proton therapy facility from the ground up. This approach optimizes resource allocation and minimizes unnecessary expenditures.

Accelerated Implementation

Converting an existing vault expedites the process of implementing proton therapy, enabling faster patient access to this advanced treatment modality.

Built-in Scalability

Designing a flexible vault creates a clear upgrade path for future proton therapy adoption. This eliminates the need for disruptive and costly renovations when the time comes to transition to proton therapy, ensuring a smooth and efficient process.

Enhanced Patient Outcomes

Proton therapy's precision and reduced side effects have demonstrated superior outcomes for specific cancer types. By proactively planning for proton therapy integration, healthcare facilities can expand access to this life-saving treatment, ultimately improving patient care and quality of life.

In essence, designing a new LINAC vault with future proton therapy conversion in mind is a strategic investment in the future of cancer care. It empowers healthcare facilities to embrace cutting-edge technology, optimize resource utilization, and provide patients with access to the most advanced treatment options available.

Conclusion

The integration of proton therapy into cancer care represents a significant advancement, but the high costs and infrastructure demands associated with traditional proton therapy centers have limited its widespread adoption. The emergence of ultra-compact proton therapy systems like the MEVION S250-FIT offers a promising solution, enabling healthcare facilities to expand their treatment capabilities without the need for extensive new construction.

This paper has explored the feasibility of designing a LINAC vault with future proton therapy conversion in mind. By strategically addressing the key differences between LINAC and proton therapy systems, and incorporating flexible design elements into the vault infrastructure, institutions can proactively plan for a seamless and cost-effective transition.

While the initial investment in a flexible vault may be slightly higher than a traditional LINAC vault, the long-term benefits are substantial. The ability to readily convert to proton therapy limited disruptions and limited construction costs can significantly accelerate the adoption of this advanced treatment modality, ultimately improving patient outcomes and expanding access to life-saving cancer care.

As proton therapy continues to gain prominence in the field of radiation oncology, forward-thinking healthcare facilities should consider the advantages of incorporating flexibility into their LINAC vault designs. By doing so, they can position themselves at the forefront of cancer treatment innovation, ensuring that their patients have access to the most advanced and effective therapies available.

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