LOW TO HIGH ENERGY BEAMSTOPS FOR APT

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Abstract

Beamstops are required for commissioning and operating linear accelerators. The family of beamstops currently being developed for the DOE-sponsored Accelerator Production of Tritium (APT) program is addressed. The operational range encompasses proton energies of 6.7 MeV at the end of the radio-frequency quadrupole RFQ to 1.7 GeV at the target/blanket, and both pulsed and cw operating modes. An additional beamstop needed on a companion test facility to validate ion injector performance has been built and operated. This was the first of the series of cw beamstops; the second is under construction and will be operational by the end of 1998. Particle stopping distance and duty factor drive the size and heat transfer capacity of these beamstops; the need for low neutron production and activation potential drives the material selection. At energies above 6.7 MeV, the preferred beamstop material is graphite with aluminum the choice for structures and helium the choice for coolant. Boronated water is the preferred shielding below about 35 MeV, but is less suitable at higher energies because of the creation of Be-7. The evolution of the low-energy demonstration accelerator (LEDA) beamstops to 11 MeV and descriptions of APT beamstops are presented with performance ramifications and the status of the hardware and testing.

1 BACKGROUND

A linear accelerator operating cw at 0.100 A has been proposed for producing tritium to replace the nation's stock-pile as it continually dwindles due to natural decay. The APT program addresses this need and is being implemented by Burns and Roe, General Atomics (GA), and Los Alamos National Laboratory (LANL) in a facility to be located at the Savannah River Site (SRS). In support of this program, an Engineering Design and Development (ED&D) program is on-going simultaneously at LANL. The baseline APT facility will produce tritium at a rate of 3.0 kg/year. A two-phase approach now under consideration would accommodate an intermediate stage whereby a 1.5 kg/year production rate could be achieved and be upgradable with minimal schedule impact. The linac uses a rf driven ion injector that feeds into the RFQ at 75 kV. The RFQ accelerates the beam to 6.7 MeV; this is followed in ascending energy levels by a CCDTL (96 MeV), CCL (211 MeV), and high energy cryo-cooled (HE) linac (1700 MeV). In the two-phase program, the first-phase facility would have the proton beam turned 90^0 at 1032 MeV and directed to the target/blanket switch-yard instead of going to 1700 MeV, turning 180^0, and returning to the same switch-yard.

Beamstops are being designed and built to accommodate each stage of the linac assembly as well as on-line tune-up operation. This began with the ED&D [1] program which requires three beamtops, two of which have been built and operated; a third is being designed. This paper gives an overview of all these beamstops outlining the key requirements, basic approach to the designs, and a summary of the work completed.

2 REQUIREMENTS AND KEY CRITERIA

The obvious prime requirement for any beamstop is to stop the accelerated particles. Not so obvious is the need to do so in a manner that addresses both the linac operation and the need to minimize the effects of nuclear interactions produced. Above a few MeV, protons will activate a target as well as produce neutrons that escape the target and activate the surrounding materials. Since proton energies up to 1700 MeV will be produced, the APT beamstops will see the full range of nuclear reactions well into the spallation regime. The object is to select the solid target material that produces the fewest neutrons. A comparison of three candidates is shown in Fig. 1. Carbon is the clear winner throughout all energies. In the same way, the vacuum vessel and structures are aluminum because of its low production of long half-life isotopes; helium is the coolant because it is transparent to the neutrons.

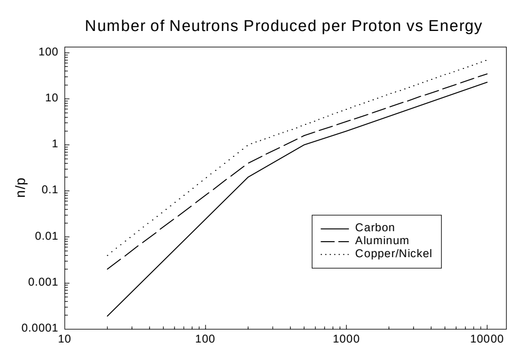

Fig. 1 Comparison of beam absorber materials

Spallation reactions with carbon produce a wide range of daughter isotopes but only Be-7 (0.48 MeV gamma, 53 day half-life) seriously affects shut-down access for maintenance or replacement. The cross section for this reaction is shown in Fig. 2. The low and intermediate energy beamstops will not accumulate much Be-7 at 0.1 % duty unless long operating times (>>6 months) are used in linac commissioning. The 1700 MeV beamstop will build up 5.4 Curies (gamma-producing) over the projected 1000 initial hours of operation at 2% power. Man-access for repair or replacement will be affected.

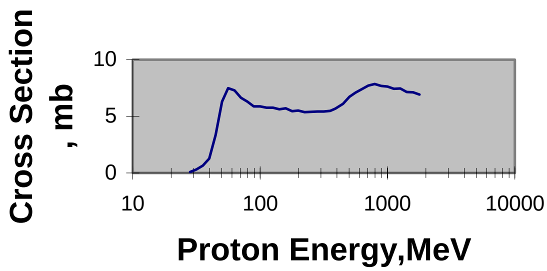

Fig. 2 Cross section for $^{12}C(p,n)^{7}Be$ reaction rises sharply above 32 MeV.

As the proton beam enters the graphite, it will penetrate as far as the initial energy will carry it. This stopping distance and the concomitant power deposition are the remaining key factors in the beamstop design. At energies up to 20 MeV, the heat deposition is essentially on the surface (2.75 mm); above this energy, the power is deposited into an ever increasing volume and depth until at 1700 MeV, 4.6 m of 1.8 g/cm^3 graphite is required to stop the beam. Fig. 3 shows the radial and axial power distributions for a 1 σ, 2.66 cm beam at 1700 MeV. This is used to design the array of cooling passages in the graphite target.

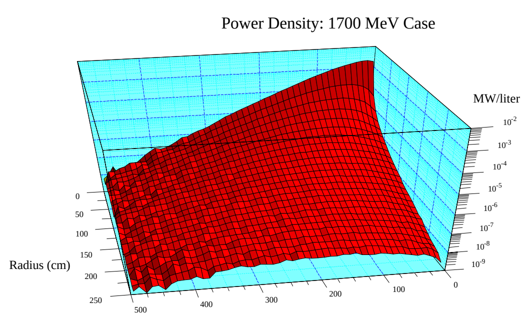

Fig. 3 Power density in graphite from a 1 σ = 2.66 cm 1700 MeV proton beam

Beamstop shielding requirements vary widely over the linac, driven by the effects of increasing proton energy. The neutron spectrum produced comes from three sources: 1) cascade neutrons that are produced from proton energies >20 MeV and can be as energetic as the incoming proton, 2) evaporation neutrons whose energies are <5 MeV, and 3) thermal neutrons arising from degradation of the cascade and evaporation neutrons. While the evaporation neutrons have an isotropic angular distribution, the cascade neutrons are forward scattered and become more so as the proton energy increases. Yields (n/p) range from $2x10^{-4}$ at 20 MeV to 2 at 1700 MeV with mostly evaporation neutrons at low energy and about half-and-half at high energy. One meter of water or concrete (4π) is adequate for neutron shielding for proton energies up to 20 MeV; it is also adequate at higher proton energy transverse to and upstream of the beam. Above 150 MeV, 6-8 m of concrete are required on the down-stream end to capture the high energy spallation neutrons. The latter may be made thinner by substituting an inner layer (20–30 cm) of steel. Unfortunately, this layer would become quite activated making it a solution of last resort.

3 COMMISSIONING BEAMSTOPS

The preliminary linac commissioning plan [2] calls for five beamstops. The first three will be used for commissioning and stored in shielded alcoves off the main tunnel after the linac has been built and tested to that point, i.e. 6.7 – 20, 211, and 470 MeV. The last two beamstops located at the end of the linac (1700 MeV. 0.1 %) and adjacent to the target/blanket (1700 MeV, 2%) are permanently integrated into the linac facility. The graphite targets of the three commissioning beamstops are cooled by thermal radiation to the respective vacuum vessels, thus eliminating the need for a window. Although larger, the 0.1% HE beamstop at the end of the linac is cooled similarly. The 2% 1700 MeV beamstop requires direct cooling of the graphite with helium and a window also cooled with helium.

The low energy beamstop will be used to commission the RFQ and as many CCDTL modules as practicable limited primarily by the increased forward scattered cascade neutrons (Fig. 4). The graphite beam target is located in the center of the shield tank and radiates the heat to the cylindrical housing which is in turn cooled by natural convection of the shield water. Air convection on the outside of the tank cools the shield water, resulting in completely passive thermal management.

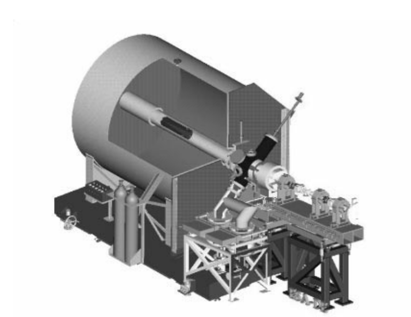

Fig. 4 Low energy beamstop to be used for commissioning at several energies starting at the RFQ

The preferred coolant is helium since it does not activate, has good heat transfer properties, and can heat-exchange to conventional cooling systems. The arrangement for the 470 and 1700 MeV (0.1%) beamstops will be designed similar to the low energy beamstop except elongated to accommodate the increased proton range and the vessel is cooled with helium. In all beamstops above 200 MeV, the shield will be concrete about 1 to 2 m thick radially to capture evaporation neutrons and 6 to 8 m thick downstream to stop the cascade neutrons.

The high energy beamstop is the final tune-up target before the beam is switched into the target/blanket. It is designed to absorb 2% of the 1700 MeV beam, or 3.5 MW. The graphite is arranged as vertical hexagonal blocks with coolant holes running transverse to the beam and spaced to keep the temperature as uniform as practicable. Helium is circulated through the blocks starting at the bottom (up-flow) with a large plenum that also acts as a support and terminating at the top where orifices are used to balance the flow through the differently heated zones. The heat is exchanged at a remote location with water to a conventional facility cooling system. The window separating the vacuum from the pressurized helium is aluminum, used to minimize the long-term activation products. It is cooled with helium through holes running transverse to the beam. The concrete shielding is similar to the intermediate energy beamstops except that special provisions are made to replace the window remotely should that become necessary.

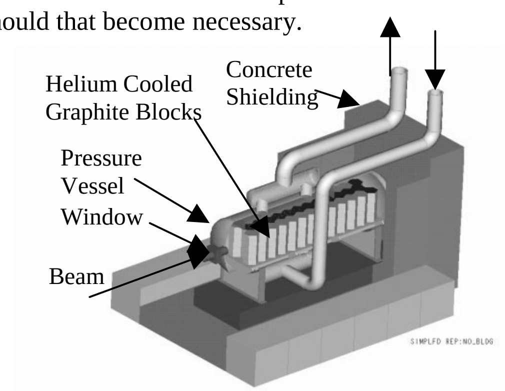

Fig. 5 High energy beamstop – 1700 MeV

4 ED&D BEAMSTOPS

Two beamstops [3] have been built in support of the ED&D program at LANL. Both use the same basic design approach to stopping the proton beam and dissipating the thermal energy, which is to use concentric thin-wall ogive (pointed arch) shapes with high velocity water flowing in the gap between them. The first one was built of copper and operated successfully in the Chalk River Injector Test Stand (CRITS) facility (Fig. 6 upper left) which reached 0.085 A at 1.2 MeV, the highest power cw beam yet achieved. The second was fabricated from electroformed nickel, chosen over copper because of the lower n/p at 6.7 MeV. This ogive is integrated into a cartridge that fits into a central chamber in an aluminum tank filled with boric acid saturated water which acts as a neutron and decay gamma shield (Fig. 6, lower right).

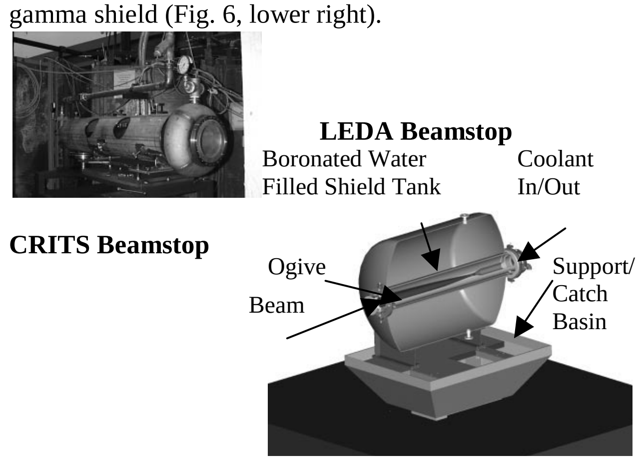

Fig. 6 Beamstops built and operated for ED&D

5 CONCLUSIONS

The development and commissioning plans for the APT linac have created unique requirements for the beamstops. These have been met with an array of designs that have taken advantage of graphite as the absorber, aluminum for structures, and helium for coolant. These materials minimize the production of neutrons and activation products which reduces the effects on worker safety and the need for remote handling. These designs give the greatest flexibility to the facility design and commissioning activities.

6 ACKNOWLEDGEMENTS

*This work was sponsored by the Department of Energy under Contract No. DE-AC04-96AL8907. The authors wish to thank GA beamstop team members Raj Acharya, Paul Wegner, Chuck Charman, Terry Figueroa, Hank Brodnick, Ralph Senior, and Craig Bystedt. We gratefully acknowledge the support of LANL staff members Joe Sherman, Herb Newman, Denise Pelowitz, Ross Meyer, Jr and Dave Hodgkins.

7 REFERENCES

[1] H. V. Smith, et al, ”Status Update on the Low-energy Demonstration Accelerator”, LINAC98 POSTER TU4014.
[2] L. Warren Funk, et al “Development of a Commissioning Plan for the APT Linac”,LINAC98 Poster TU4012
[3] T. H. Van Hagan, et al, “Design of an Ogive-Shaped Beamstop”, LINAC98 Poster TU4091.