Evaluation of Hybrid Brass/Stainless-Steel Apertures for Proton Therapy

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Introduction

Brass is most common materials used for apertures for proton therapy because Brass is easy to machine and has reasonable stopping power. Stainless steel is inexpensive compared with Brass and hard to machine. A hybrid Brass/stainless steel (SS) aperture (figure 1) design could reduce proton therapy costs without alteration to the current treatment planning and QA procedure. This project is to evaluate suitability of hybrid brass/stainless steel (SS) aperture design.

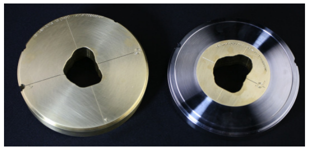


Figure 1: Brass/stainless steel aperture from .decimal

Hypothesis

The aperture function is to shape the incoming proton beam in BEV. So aperture should completely stop proton beam outside BEV with enough safety margin. The thickness to stop 235 MeV protons is 65 mm for Brass and 63 mm for Iron. The snout design of proton system with Brass aperture should be enough to completely stop proton beam when stainless steel aperture is used.

The dominant source of neutron dose is generated from the patient specific aperture. The aperture-produced neutron doses from Iron and Nickel, which are tow major components of stainless steel, are little less then Brass.[1] SS aperture will not introduce more neutron dose associated second-cancer risks compared with Brass.

Patient specific aperture becomes radioactive due to proton introducing isotopes. Residual activation of the aperture should decay within background activation before disposals. According to cross section measurement for proton-induced reactions [2-3], proton-induced residual activation of SS aperture should similar or less than that of Brass aperture.

Aperture thickness will affect the lateral penumbra. Hybrid aperture should not adversely affect the lateral penumbra.

Method

Stopping power ratio of a standard SS (SS304) was calculated and measured using an IBA PT system. Proton beams at different proton energies were penetrate solid SS aperture. Water equivalent range (WER) of proton beams was from 9 cm to 27cm. Parallel plane chamber (PPC05) was utilized to detect the output of proton beam after the apertures. The leakage after two 18cm SS apertures for max available proton energy (32 cm WER) was also measured.

Proton-induced residual radionuclides of Brass and SS apertures after 10 CGE dose were monitored for one week. Potential range differences in SS/brass interface regions of the hybrid design were investigated using EBT2 film.

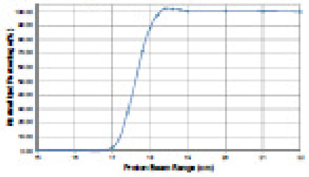
Results

The beam range limits for each aperture slab thickness were determined and shown at Figure 2.

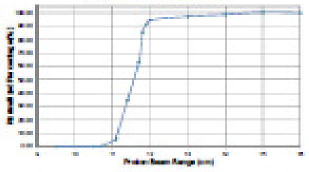
The linear stopping power ratio for SS304 and brass were calculated to be 5.46 and 5.51 respectively. Measured stopping power ratios of SS and brass were 5.38 and 5.56 respectively, agreeing to their calculate values to within 1.5% and 1%.

18cm SS aperture (3.25 cm) was water equivalent to 18.1 cm corresponding to 4cm safety margin. One and two 25cm SS apertures (2.25 cm) were water equivalent to 11.9 cm and 23.8 cm corresponding to 3.2cm and 2.9 cm safety margin.

(a) Dose after one 18cm aperture



(b) Dose after one 25cm aperture



(c) Dose after two 25cm aperture

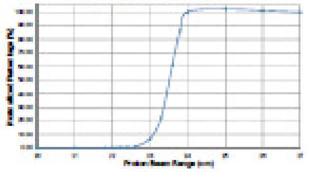


Figure 2: Percentage dose after (a) one 18cm aperture, (b) one 25 cm aperture, and (c) two 25cm aperture.

Leakage after two 18cm SS apertures for max available proton energy was about 1.68%. Beam range limits of brass aperture slabs used at our institution, with safety margin allowances for material composition and delivered beam range uncertainties, may therefore be applied directly to SS aperture slabs.

Aperture thickness will affect the lateral penumbra. Hybrid aperture should not adversely affect the lateral penumbra. Film dosimetry (Figure 3) reveals no discernible range variations across the SS/brass interface regions (Figure 4).

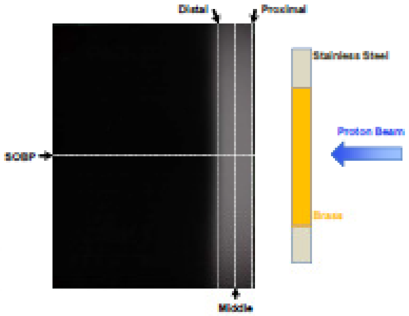


Figure 3 Gafchromic EB3 film after Brass/stainless steel aperture

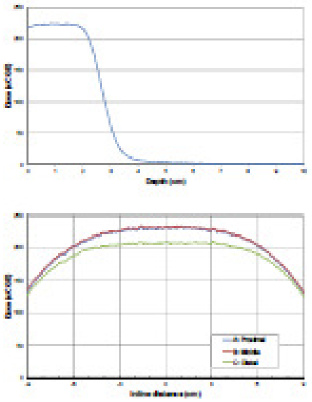


Figure 4 (top) Depth dose and (bottom) three inline profile after Brass/stainless steel aperture

Proton activation of SS produces shorter half-life radio isotopes. Measurements of SS and brass activation decay characteristics (Table 1 & 2) show that SS activation decays at a faster rate than brass, therefore requiring no changes in radiation protection requirements on material disposals.

Table 1: Radiation activity at surface (mR/hr)

Time	SS_A	SS_B	SS_C	SS_D	BR_A	BR_B	BR_C	BR_D
0	300	300	300	300	116	112	110	36
0.18					70	61	61	21
0.30	75	73	80	30	68	42	40	8
1.00					15.5	15	13	4
1.30	30	30	30	7.8	10	8	7.8	3.8
2.40	7.8	7.8	7.8	3	4.8	4	3.8	1
1D 7:00	1.8	1.8	3.8	1	1.3	1	0.8	0.48
2D 7:00	0.7	0.8	0.8	0.3	0.4	0.4	0.3	0.14
3D 7:00	0.8	0.8	0.45	0.28	0.3	0.28	0.2	0.12
4D 7:00	0.58	0.48	0.4	0.33	0.26	0.2	0.15	0.1
5D 7:00	0.5	0.4	0.35	0.3	0.25	0.2	0.15	0.08
6D 7:00	0.48	0.4	0.35	0.2	0.2	0.18	0.13	0.07

Table 2: Table 1: Radiation activity at 1 foot away (mR/hr)

Time	SS_A	SS_B	SS_C	SS_D	BR_A	BR_B	BR_C	BR_D
0	35	30	30	13	10	8	6	3
0.18					4	3.8	3.8	1.4
0.30	40	30	30	8	3	1.7	1.4	0.7
1.00					0.8	0.8	0.7	0.2
1.30	1.1	1	0.8	0.4	0.4	0.4	0.3	0.2
2.40	0.4	0.3	0.38	0.2	0.2	0.2	0.2	0.1
1D 7:00	0.18	0.15	0.3	0.14	0.21	0.2	0.14	0.08
2D 7:00	0.1	0.08	0.08	0.05	0.08	0.08	0.05	0.028
3D 7:00	0.08	0.08	0.08	0.04	0.08	0.045	0.05	0.03
4D 7:00	0.05	0.05	0.04	0.03	0.05	0.045	0.04	0.028
5D 7:00	0.05	0.05	0.05	0.028	0.04	0.03	0.03	0.02
6D 7:00	0.05	0.05	0.05	0.03	0.04	0.03	0.03	0.01

*A and B are surface of aperture [illegible]. C and D are surface of aperture [illegible]. A is read close to proton source, D is read far away.

Conclusions

The hybrid brass/SS aperture design is suitable for clinical use to replace the current brass apertures for all treatments except those using maximum beam ranges. Existing aperture disposal procedures to satisfy radiation protection mandates apply adequately to these apertures.

Acknowledgments

Hybrid Brass/Stainless-Steel Apertures were provided by .decimal, Inc.

Reference

1. D.J. Brenner, C.D. Elliston, E.J. Hall, H. Paganetti "Reduction of the secondary neutron dose in passively scattered proton radiotherapy, using an optimized pre-collimator/collimator", Phys. Med. Biol. 54, P6065-6078, 2009

2. S. Pearlstein, "Medium-energy nuclear data libraries: a case study, neutron- and proton-induced reactions in 56Fe", The Astrophysical Journal, 346: 1049-1060, Nov 15, 1989

3. J.M. Sisterson, J. Vincent, "Cross section measurements for proton-induced reactions in Fe and Ni producing relatively short-lived radionuclides at E=140-500 MeV", Nuclear Instruments and Methods in Physics Research: Beam Interactions with Materials and Atoms, Vol 251, Issue 1, Sep, 2006