Conditions Around the Proton Beam Window of the Spallation Neutron Source

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ABSTRACT

A proton beam window separates regions with different vacuum conditions in the last part of the path of the proton beam. Very near to the window an instrumentation box for beam diagnostics is going to be located. All components comprising the proton beam window assembly are going to be located in a box, which has to be serviced regularly through a channel perpendicular to the direction of the beam (2mA 1 GeV protons). Due to the strong effects of the proton window, the engineering design of this part of the target facility requires detailed calculations of the heating and dose distributions for beam on and off conditions as a function of the materials for the window and the shielding of the instrumentation box. A summary of the results, relevant to decisions to be taken regarding the design and operation of the facility, are presented .

I. INTRODUCTION

A proton beam window[1] (comprised of two sections, each ~ 2 mm thick, separated by cooling water) separates regions with very different vacuum conditions in the last part (~ 2m before the Hg target) of the path of the proton beam. Very near to the window an instrumentation box for beam diagnostics is going to be located. All components comprising the window assembly are located in a box, which has to be serviced regularly through a channel perpendicular to the direction of the beam (2mA 1 GeV protons).

The interaction of the proton beam with the window originates a shower of particles that affect the media around it. The engineering design of this part of the target facility requires detailed calculations of the conditions around the proton beam window as a function of design parameters like materials for the window and geometry and materials for the shielding of the instrumentation box. There is also interest in the "noise" produced by scattered particles in the "harp" (tiny wires to measure the beam profile).

A general view of the current design is shown in Figure 1. The candidate materials for the proton beam window are inconel and aluminum; tungsten and stainless steel are the materials for the shielding of the instrumentation box. Heating rates and doses distributions were calculated for beam-on conditions with the MCNPX code[2]. Neutron fluxes and history tapes were then saved to compute[3] the buildup and depletion of radioactive isotopes as a function of the operating time of the beam and the time since the beam is shut off. The isotopic inventory was then used to compute the activation gamma source for the calculations of the dose for beam–off conditions. A summary of the results, relevant to decisions to be made regarding the design and operation of the facility, are presented in the following sections.

II. HEATING OF AND MATERIAL FOR THE SHIELDING OF THE INSTRUMENTATION BOX

Calculations were done for rectangular shields made of tungsten (W) and 304 stainless steel (SS304) around the 5x11" duct for the proton beam. Thicknesses are 18.4 cm horizontal, 22.8 cm (average) vertical and 19.5 cm in the direction of the beam (between the frame of the window and the instrumentation box). Table 1 shows a summary of the energy deposited in the components of the instrumentation box for the cases of the two candidate shielding materials and for the case of the inconel window. The table also shows the effects of an additional W shield around the frame of the proton window (a rectangular collar). The heating in the shielding itself is shown in Figure 2.

Table 1: Effects of the Shielding on the Heating of the Instrumentation Box (1 GeV p)

	No Shielding		*Relatives Values with Shielding*		
Region	***MeV/p***	***Error MeV***	***W+W Collar***	***W***	***SS304***
Wall Target Side	0.112	0.017	0.062	0.476	0.565
Wall Central	0.028	0.009	0.118	1.080	1.095
Wall Beam Side	0.076	0.014	0.163	0.446	0.608
Sum	0.216		0.105	0.543	0.648

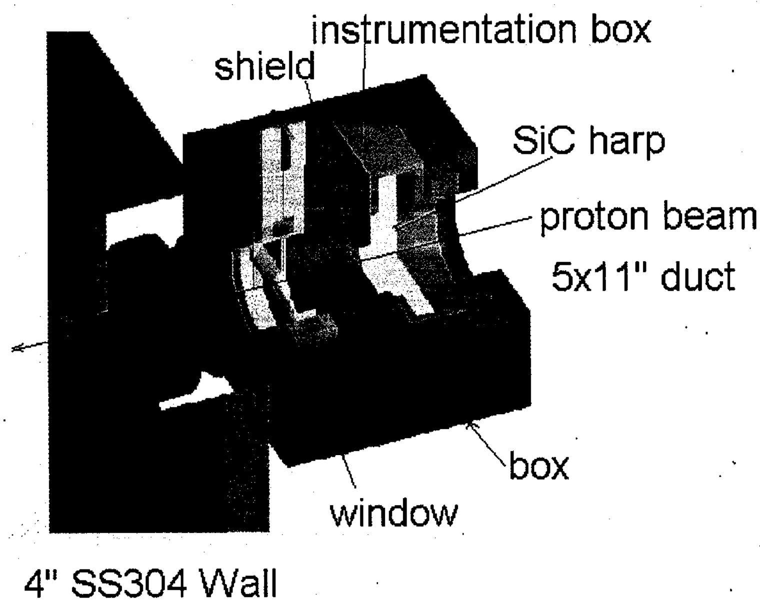

Figure 1: General view of the regions around the proton beam window. The box is attached to the wall with a bellows seal and a clamp and it is located inside a shielded service channel perpendicular to the beam.

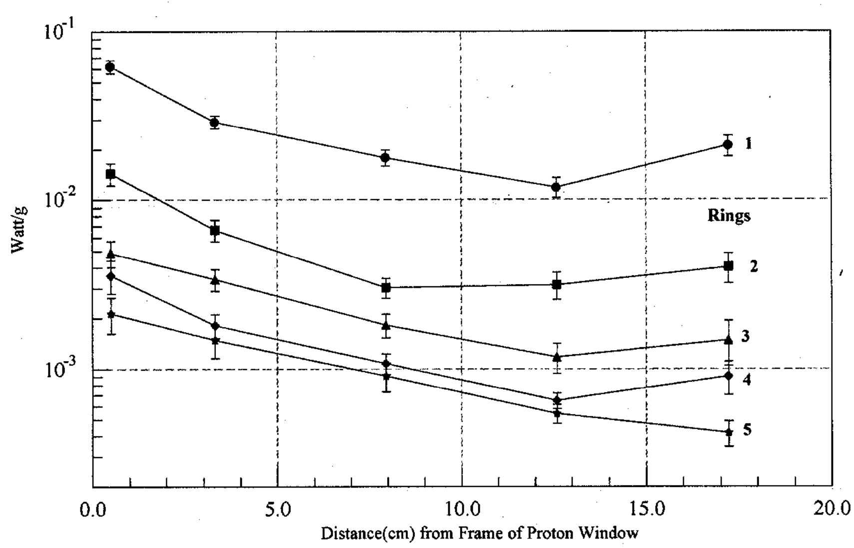

Figure 2: Heating of the SS304 shield for concentric rectangular rings of approximate equal thickness around the 5x11" beam duct (for an inconel proton beam window)

III. EFFECTS ON THE MEASUREMENT OF THE PROTON BEAM

The "harp", a collection of fine wires for beam measurements and diagnostics, was modeled as a 0.5 mm sheet of SiC at the center of the instrumentation box. Two calculations were performed: one, with the proton beam crossing the sheet in the nominal position which gives the "signal", i.e. the heating rate at the region of the sheet where the source is above 5%; and the other, with the source slightly shifted to the side of the sheet which gives the "noise", i.e. the heating rate in concentric annuli around the beam produced by secondary particles originated by the interaction of the protons with the window. The plot of the ratio of these two calculations in Figure 3 gives then the expected noise of the measurement

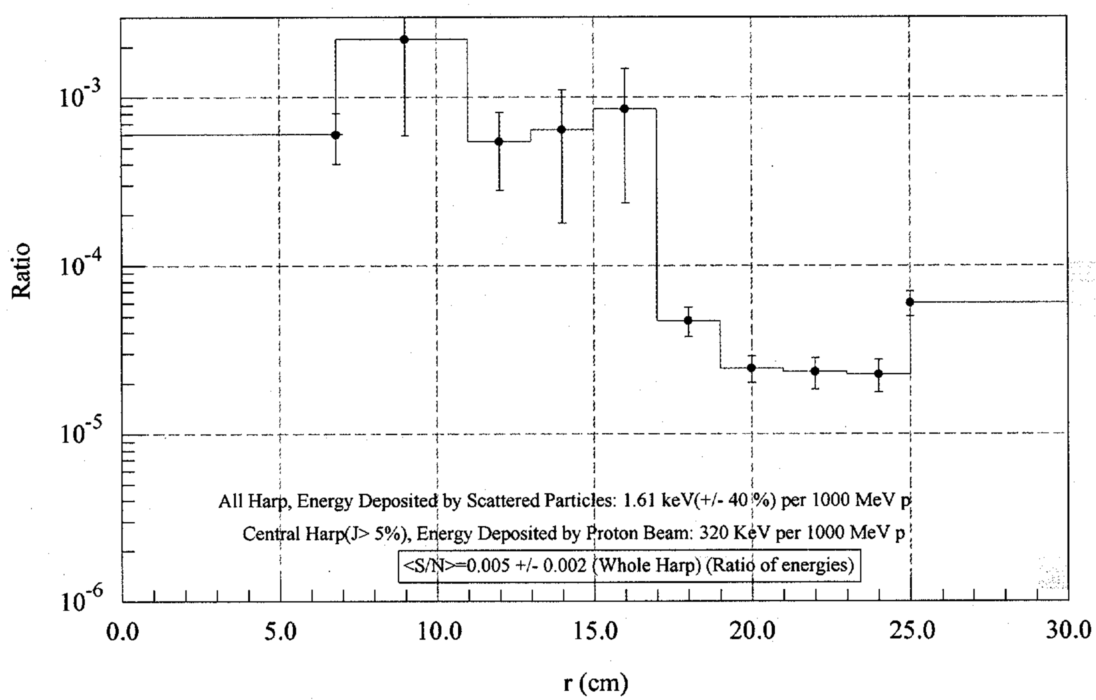

Figure 3: Ratio of the heating in the "harp" produced by the secondary radiation and the proton beam. Conditions inconel window, W shield (with collar)

IV. EFFECTS ON THE DOSE DISTRIBUTION AROUND THE WINDOW

The interaction of the beam with the proton beam window produces an intense radiation field in the service channel for the proton beam window assembly box. Neutron and gamma doses were computed for beam on and off conditions. History tapes from MCNPX were analyzed to compute the activation in the vicinity of the proton beam window in order to calculate the beam-off doses as a function of the operating time of the facility and the time after the beam is switched off. Figure 4 summarizes the results for both cases, beam-off conditions are 0 days after 10 full months of operation. For other conditions Figure 5 indicates the dependence of the activation source on the time after shutdown. Note that before shutdown the dose is mainly due to neutron interactions while the gammas are the main source for the doses at shutdown conditions.

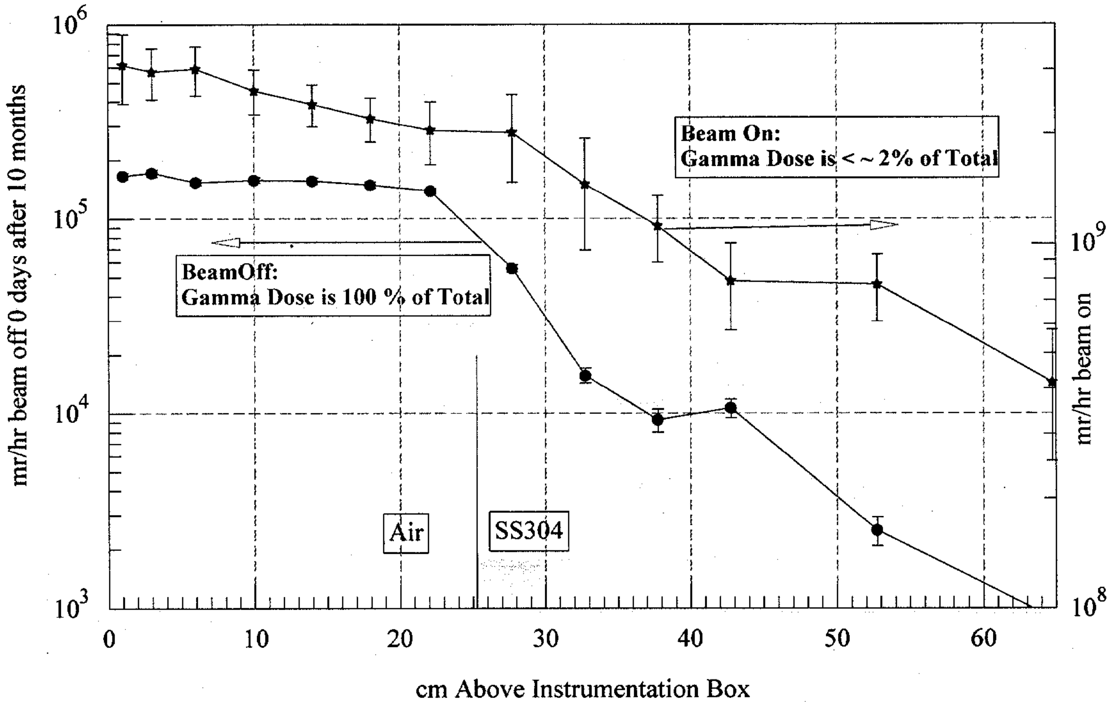

Figure 4: Doses along the service channel (above the instrumentation box). Beam-on values correspond to 2 mA of 1 GeV protons. Beam-off values correspond to 0 days after 10 full months operation. Conditions: inconel window, W shield (including collar).

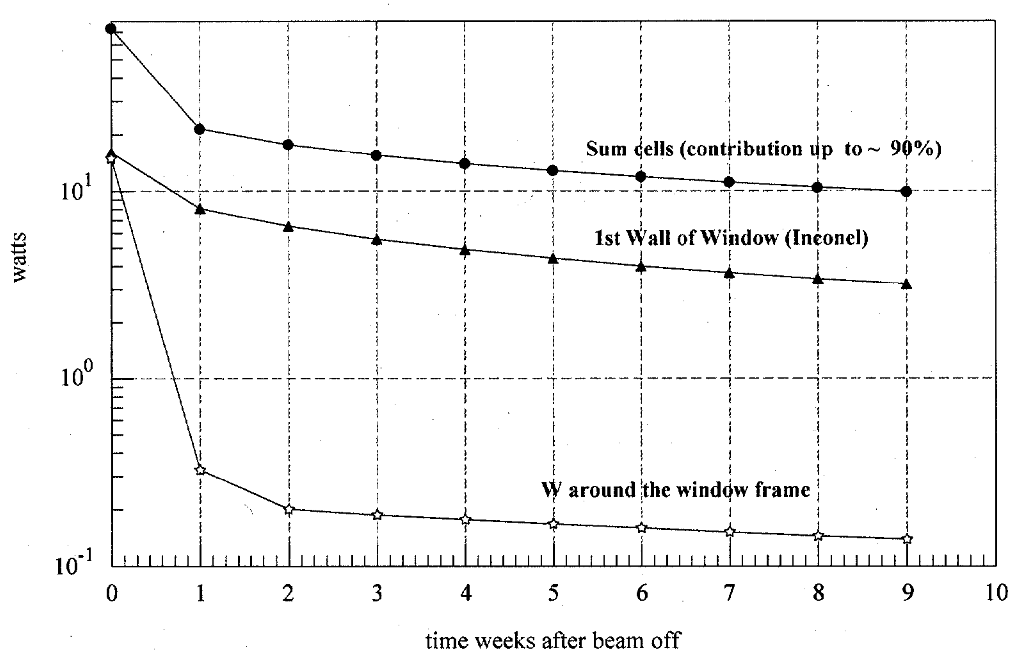

Figure5: Gamma activity as a function of time after shutdown (from 2 mA 1 GeV proton beam for 10 full months)

V. EFFECTS OF THE MATERIAL FOR THE PROTON BEAM WINDOW

Table 2 shows the considerable heat generated in the region around the proton beam window by the secondary radiation generated after the interaction of the protons with the 2 inconel walls (~ 2mm each). A high proportion (~92 %) of the heat is generated very near the interaction: the walls of the window, its coolant, the shield and the wall of the proton beam window assembly box located down stream (the target side). An aluminum window (2 walls 3 mm thick) would reduce the heating by ~ 40 %.

Table 2: Heat in and around the Box with the Proton Beam Window (2mA 1 GeV p)

	Inconel Window		Al Window		
Region	**Kw**	**Fraction**	**Kw**	**Fraction**	**Al/Inconel**
Wall Box Target Side	2.42	0.10	1.69	0.12	0.70
First Wall Window	7.99	0.33	3.92	0.27	0.49
2nd Wall Window (Water)	1.08	0.04	0.96	0.07	0.89
3rd Wall Window	8.52	0.35	4.17	0.29	0.49
W Collar Shield	0.73	0.03	Not Present	---	
W Shield	1.71	0.07	1.45	0.10	0.85
Total Entire Region (BOX)	**24.5**		**14.6**		0.60
Fraction for regions shown here		0.92		0.84	

VI. EFFECTS ALONG THE BEAM PATH

The heating totals in Table 2 refer exclusively to the region of the proton beam window assembly box. The box itself is connected to a flange from the vessel with a bellows seal and a clamp (see Figure 1 for details). These pieces (SS304) are also down stream and consequently are affected by the secondary radiation originated in the walls of the window. Table 3 shows the details, with an additional ~7.7 Kw heat generated in these parts.

Table 3: Heat in Flanges, Clamp and Connectors Box/Vessel

	Total Heat Source for a 2 mA Beam (1GeV p)		
Region	**Watts**	**Error Watts**	**Watt/g**
Flange from Box			
First inch	56.39	5.33	0.166
90 degree fin	52.34	5.57	0.1356
First corrugation	42.18	4.95	0.1227
90 degree fin (end 2nd inch)	65.15	6.09	0.1688
3rd inch	69.89	6.27	0.2057
90 degree fin	52.20	4.92	0.1352
2nd corrugation	46.53	5.50	0.1353
90 degree fin (end 4th inch)	63.02	6.01	0.1633
End Flange From Box	262.70	15.50	0.1381
Rest			
Clamp	2171.14	111.60	0.0411
Flange from Vessel	4702.66	207.39	0.0735
7x13" Connector to Vessel	106.38	12.77	0.0685
Sum	7690.58		

VII. CONCLUSSIONS

The secondary radiation originated by the interaction of the beam with the walls of the proton beam window generates considerable heat in near regions located down stream of the beam window. Heat is also generated around the instrumentation box upstream. Because of the presence of measuring devices this heat, although less intense, makes additional shield necessary. This part of the facility has to be serviced periodically through a vertical channel. It was necessary then to compute the dose nearby for beam-on and beam-off conditions. The proton beam window then not only affects the performance of the facility, but also its maintenance. The calculational data depends on materials and geometries. This information, evaluated by the engineering design team, is use in an iterative scheme, to redefine the engineering details.

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