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Design of the NSNS Collimator System

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1.5.8 COLLIMATION and SHIELDING

Beam collimation will be carried out by a self-shielding collimator system. In this system beam halo proton are captured in the collimator, and a small fraction of the original protons and secondary particles are allowed to escape from the collimator. This goal is acommplished by designing the collimator in such a manner that halo protons can penetrate to approximately the center of the collimator, and are stopped at this localtion. Thus the secondary particles will be generated as far as possible from any outside boundaries of the collimator. The above concept leads to a layered structure, with the outer layers in the direction of the proton beam being relatively transparent to protons, and becoming increasingly black with depth. In addition the outer layers should be black to neutrons, thus minimizing any neutron leakage. Finally, the production of residual activity in coolant streams, and surrounding air should be minimized.

Additional shielding might be required to minimize radiation levels during periods of maintenance. This will be accomplished by movable shielding blocks, which will be placed around the collimators should this be necessary.

1.5.8.1 COLLIMATOR

The design goals for the collimator are:

1) Halo proton attenuation by a factor of 1.0^{-4}
2) Minimize production of secondary radiation, and its subsequent leakage,
3) Remove heat (1 kW),
4) Mechanically compatible with ring operation (mitigate fatigue failures),
5) Minimize radiation damage and secondary activity.

In order to meet these goals a layered structure was designed. The design consists of initial layers (in the direction of the proton beam path) which are transparent to protons, and become progressively less transparent (blacker) with depth into the collimator. In addition a high density (iron) shield will be added around this structure, particularly in the backward direction, to attenuate any reflected protons. The protons are thus stopped in the approximate center of the collimator, and thus the bulk of the secondary particles will also be generated there. Since these particles are primarily isotropic their leakage length path will be maximized in this manner. In the case of neutrons a black layer is included at each end in order to further minimize their leakage in the direction of the beam. This design will therefore minimize the activation of surrounding accelerator components.

The conceptual design is shown on Figure 1. The protons travel from left to right, with the beam confined primarily to the inner diameter of the collimator. Halo particles are found between the collimator inner diameter and the beam tube inner diameter, and are assumed to pass into the collimator volume. On their way into the collimator the halo particles will first encounter a graphite transition piece between the beamtube diameter and the collimator diameter. This piece is 20 cm long, and has a conical front end. Protons at the operating energy pass through graphite with relative ease, and hardly produce any secondary particles. The collimator containment vessel wall fits behind the graphite piece, it is 1 cm thick and made of steel. The next 15 cm consist of a plate structure of alternating layers of steel clad B_4C infiltrated graphite and cooling water. The coolant fraction in this structure is 15%, and consists of borated light water. It is seen that this region is relatively transparent to high energy protons, but lower energy neutrons, such as those which might result from a spallation reaction, would be slowed down in this region and be absorbed in the boron. It would thus be black to low energy neutrons.

All the zones to this point have the same composition in the radial direction. The following two zones have a radial variation at a radius of 20 cm. Within the 20 cm radius they consist of randomly packed sphere cooled by borated light water, and outside this radius they consist of iron. This arrangement is choosen to ease the assembly of the collimator, ensure heat removal, and minimize the cost. Randomly packed beds of particles are particularly efficient at heat transfer, since their area per unit volume is greater than any other practical arrangement of the same characteristic dimension. Furthermore, the cost of small spheres of either molybdenum or tungsten is lower than machined discs of the same material. The void (coolant in this case) fraction of randomly packed spheres is approximately 38%, thus the solid fraction in these zones will be 62% of solid. The first particle bed zone will consist of 3 mm diameter molybdenum particles, with a length of 80 cm. The protons will loose the bulk of their energy in this zone, and since the production of neutrons per proton is modest off molybdenum at these energies the secondary porduction of neutrons is relatively low. Once the protons have lost the bulk of their energy in the molybdenum particle bed zone they will enter a 45 cm long tungsten particle bed zone. In this zone the protons give up most of their remaining energy, and their energy is low enough that the neutron production is modest. However, there is a probability of generating secondary protons in addition to the neutrons. Fortunately the yield of secondary protons is low compared to the neutron yield, due to the fact that the protons have to over come the potential barrier before escaping the excited nucleus.

Finally, the back 15 cm of the collimator consists of the same steel clad B4C infiltrated graphite and borated water structure used in the front 15 cm. The collimator is encased in 20 cm of solid iron on all sides except the front, where the thickness is increased to 65 cm. The collimator thus has an overall radius of 75 cm and a total length of 252 cm (including the iron shield. The thick iron shield act to stop atenuate any protons which are reflected or are created within the collimator. In addition any high energy neutrons which may escape the collimator will be attenuated in these shields, thus minimizing the activation of the surrounding (upstream and downstream) ring components. It is felt that this collimator design will fullfill the above mentioned design goals.

The thick shield should minimize neutron leakage, which in turn will minimize the activation of the air in the tunnel. The primary activation products are ^{41}Ar and ^{16}N, with the nitrogen decaying essentially immediately, while the argon is still active for approximately a day following shutdown. This situation can be ammeliorated by venting the tunnel air, and maintaining it at a slightly lower pressure. The only other activated material which can leave the collimator is the cooling water. Potentially ^{7}Be and ^{3}H are formed and ciculated in the coolant. If contained the ^{3}H should be undetectable, since it emmits an electron upon decaying to ^{3}He. However, the ^{7}Be decays via a gamma ray (477.6 keV) and a half-life of 53.28 days. This poses a more serious problem, particularly for maintenance work. For the above reasons the cooling water will be cooled in a closed cooling loop via an intermediate heat exchanger. The maximum heat load from a collimator is 1 kW. If a temperature rise of $5^{0}C$ is assumed (Tin = $30^{0}C$, and Tout = $35^{0}C$) a flow rate of approximately 2.0 gal/min is required. This implies a moderate heat removal system for the design basis conditions. Table 1 shows the dimensions and material masses implied by the above design.

The performance of the above collimator design is shown in Table 2. This table shows the backward (-1,0) and forward (0,1) proton currents in the halo zone of the beam (radius greater than 5 cm). at various axial positions along the collimator. It is seen that for the example considered here the halo consitutes a fraction of 0.077 (axial position 14, direction (0,1)). This fraction decreases monotonically to 1.0(-6) at the back end of the collimator. In addition the leakage out of the front end of the collimator is also seen to be 1.0(-6) (axial position 40, direction (-1,0)). Within the collimator it is seen that the proton current in the backward direction varies, with a maximum at the interface between the shield and the collimator containment vessel. The need for the thick iron shield is thus seen to be necessary. Thus the proton leakage out of the back and front of the collimator meet the design goal set for it.

Estimates of the energy deposited in the collimator indicate the the bulk of the power will be generated in the inner 20 cm of the graphite zone (25%), the front iron shield (10%), the molybdenum particle bed (36%), and the entire graphite transition piece (20%). All these zones need to be cooled by the cooling water. The graphite and molybdenum zones are inside the collimator, and are cooled by the cooling water in the collimator. The graphite transition piece and the iron shield are cooled by a cooling coil passing along the interface between these two zones.

Finally, the activation of selected zones is shown in Table 3. The value shown in this table assume that the machine has operated for 180 days at full power, and the activity in curies is shown for 1 hr, 1 day, 7 days, and 30 days. It is seen that the Quadru-pole and Di-pole magnets have a low activation. The primary activation product being ^{51}Cr, ^{54}Mn, ^{56}Mn, ^{55}Fe, ^{59}Fe, ^{65}Ni, ^{62}Cu, and ^{66}Cu. In the iron zone of the magnet the same activation are important, except for Cu and Ni. Activation of the solid components within the collimator are well shielded, and the gamma ray leakage out of its sides is approximately six orders of magnitude below the source intensity. Furthermore the activation is contained within the collimator structure. If for some reason the radiation levels should be too high (for maintenance work) then it is possible to arrange for movable shields to be temerarily placed around the collimator. It is seen that the air activation is quite modest, and is dominated by the argon activation following 1 hr. The molybdenum particle bed is the most activated part within the collimator. The most significant activation products are (above 1 curie following shutdown) given below by element and atomic number.

Carbon	(11)
Oxygen	(14,15)
Copper	(62,64)
Zinc	(63,65,)
Gallium	(66,67,68,70)
Germanium	(68,69,71)
Arsenic	(70,71,72,73,74)
Selenium	(72,73,75)
Bromine	(75,76,77,78,80)
Krypton	(76,77,79)
Rubidium	(79,80,81,82,83,84,86)
Strontium	(81,82,83,85)

Yittrium	(83,84,85,86,87,88,89m,90,91,92,93,94)
Zirconium	(85,86,87,88,89,95,97,98)
Niobium	(88,89,90,95,96,97,97m,98,99)
Molybdenum	(89,90,91,91m,93m,99,101)
Technecium	92,93,94,95,96,99m,101)

The above long list is reduced when only those isotopes are considered which decay by emmitting a gamma ray with an energy between ,85 and 1.25 MeV. This is generally the peak intensity of the emmitted gamma rays. Thus although gamma rays of higher energy are emmitted, their intensity is significantly reduced. The reduced list includes:

Vanadium	(48)
Manganese	(52)
Cobalt	(56,60)
Zinc	(65)
Gallium	(68)
Germanium	(69)
Arsenic	(71,72)
Bromine	(76)
Rubidium	(82,84,86)
Strontium	(83)
Yittrium	(89,90)
Zirconium	(89,95)
Niobium	(88,90,95,96)
Molybdenum	(93m,99,101)
Technecium	(93,94,95,96)

Several isotopes appear on the second list which did not appear on the first list. This is because their activity is low, and thus they do not contribute significantly to the overall activity, but do contribute to the gamma ray source of interest. The activation due to high energy (greater than 1 MeV) gamma rays is approximately half the overall activation. The remainder being primarily due to beta decays.

The conceptual collimator design outlined above can meet all the goals, and can form the basis for a final design study.

Table 1 - Masses and overall dimensions for collimator

Masses (kg)

Component	Mass
Graphite transition piece	18
Front iron shield	8939
Collimator vessel	900
Graphite/Borated water	800
Molybdenum/Borated water	618
Iron	5212
Tungsten/Borated water	623
Iron	2852
Radial iron shield	10240
Back iron shield	2770
Total	32972

Dimensions (cm)

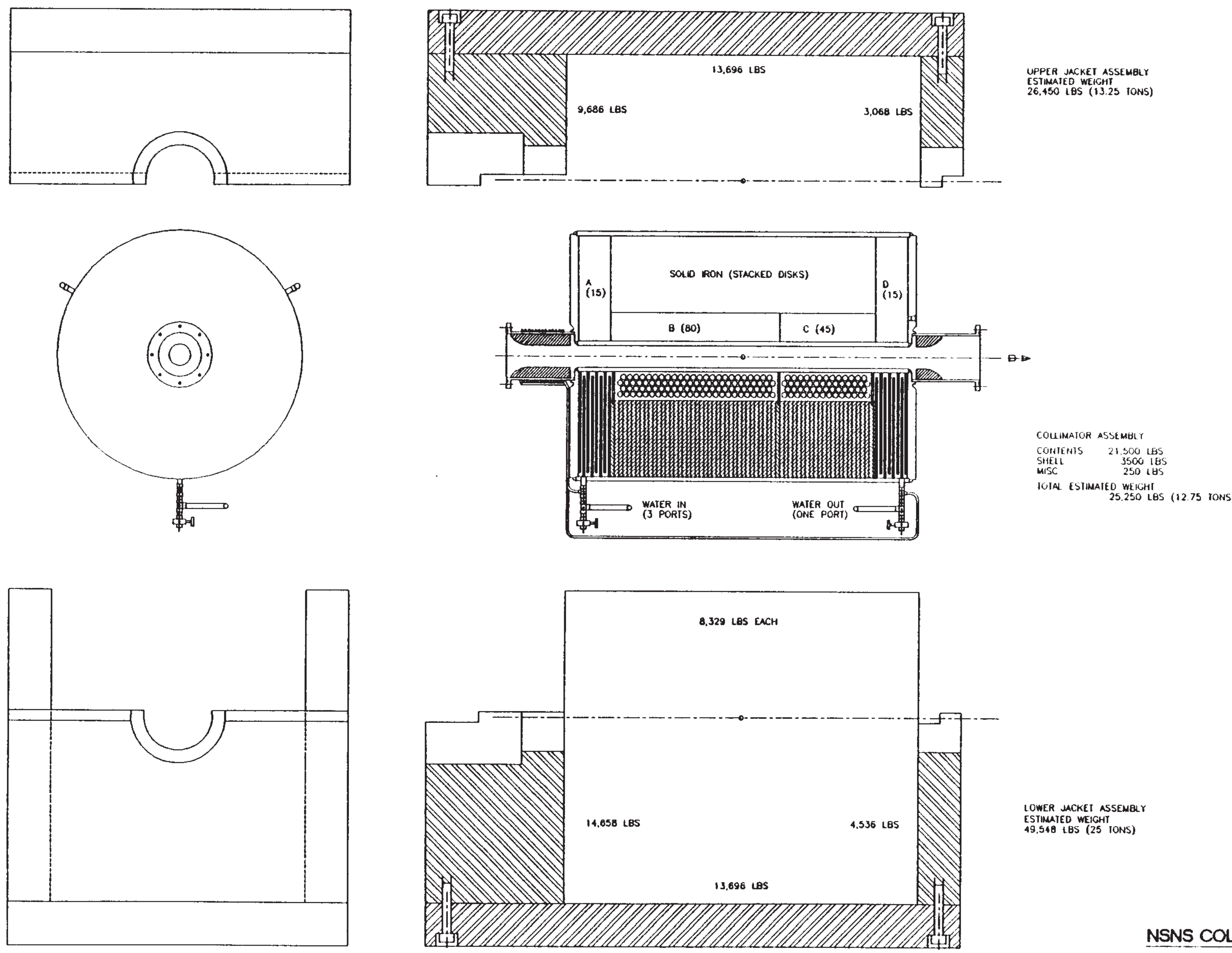
Graphite transition piece	20 (L)
Front iron shield	45 (L)
Collimator vessel	150 (OD)
Graphite/Borated water	15 (L)
Molybdenum/Borated water	80 (L) x 20 (OD)
Iron	80 (L)
Tungsten/Borated water	44 (L) x 20 (OD)
Iron	44 (L)
Radial iron shield	155 (L) x 190 (OD)
Back iron shield	20 (L)

Table 2 Performance of the collimator
(protons crossing surface/source proton)

Surface	Backward	Forward
0.0	1.0(-6)	~
45.0	3.32(-4)	7.68(-2)
65.0	5.07(-4)	7.61(-2)
81.6	3.04(-4)	5.14(-2)
162.0	5.0(-6)	1.1(-4)
206.0	~	1.2(-5)
221.0	~	6.0(-6)
242.0	~	1.0(-6)

Table 3 Activation of selected components
(curies)

	Time after shutdown following 180 days of full power operation			
	0 days	1 day	7 days	30 days
Quadru-pole (Cu/Fe)	507	118	6	5
Quadru-pole (Fe)	21	8	8	7
Air front	.03	.002	~	~
Graphite transition				
Graphite/H2O (40 cm OD)				
Mo. part. bed (40 cm OD)	21800	13676	4260	1345
W. part. bed (40 cm OD)	2275	920	300	225
Air back	~	~	~	~
Di-pole (Cu/Fe)	1.4	.5	~	~
Di-pole (Fe)	.5	.2	.2	.2



NSNS COLLIMATOR

ROUGHLY PER INFO BY H LUDEWIG, BNL-DAT

1/16 PLOT (44X34) JCWalker 3/13/97

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