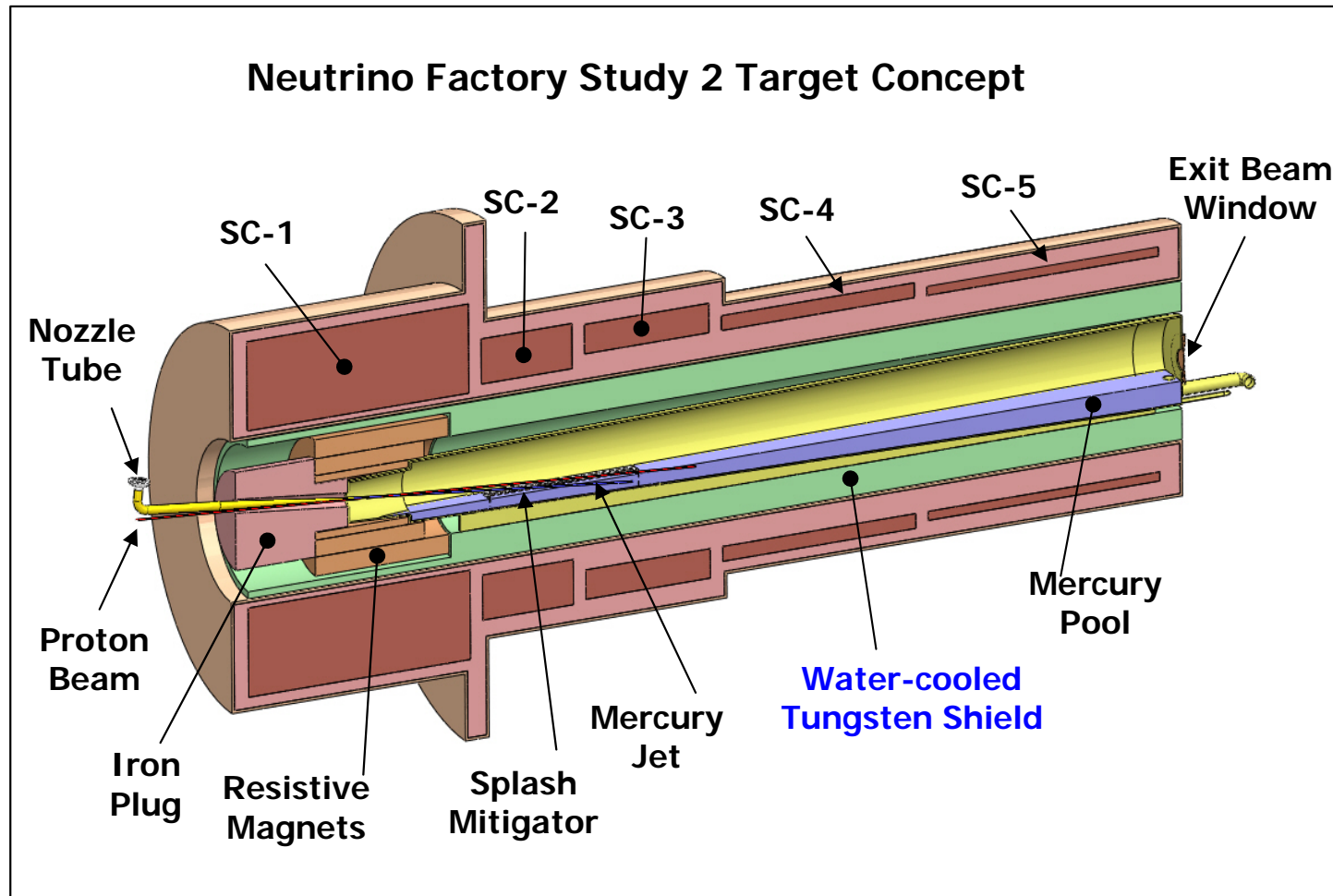


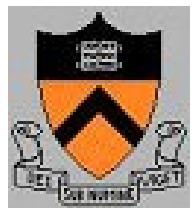
Materials for the Target System Internal Shield



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General Issues

Baseline beam power on target is 4 MW.

Where is this power dissipated?

≈ 15% in the (high- Z) target.

≈ 75% in the internal shield of the target system (including dump and Cu magnet).

≈ 10% in the front end (downstream of the target system exit beam window).

Should some of the "front-end" magnets also have internal shields?

Issues:

Heating/quenching of the superconducting magnets.

Radiation damage to/failure of the superconducting magnets

Activation of materials (which must eventually be disposed of)

Failure modes of the target system in which radioactive materials might be released.

Design principle regarding activation: ALARA = "As low as reasonably achievable".

But, what is "reasonable"?

Best to use low- Z materials.

Thickness of a low- Z shield ≈ 6-10 times that that of high- Z .

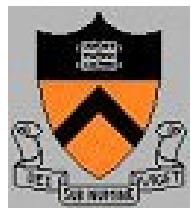
⇒ (?) 10-fold higher cost of target system if use low- Z (graphite/water) shield.

If make target low- Z , but use high- Z shield, reduce activation by only ≈ 10%.

Baseline remains high- Z target and high- Z shield.

The internal shield must be cooled by fluid flow: Water or (?) mercury or (?) Pb/Bi.

The coolant should enter and exit the upstream end of the target system.



Candidate Shield Materials

The shield operates primarily via dE/dx loss of traversing charged particles.

High-energy neutrons and K_{long} are little shielded.

Figure of merit is $\text{MeV/cm} = \text{density} \times \text{MeV}/(\text{g/cm}^2)$.

For shields based on $\approx 1\text{-mm-diameter spheres} + \text{liquid}$, assume liquid is 40% by volume.

Random sphere packing:

http://puhep1.princeton.edu/~mcdonald/examples/detectors/song_nature_453_629_08.pdf

Tungsten + water is not so good, tantalum is OK:

http://puhep1.princeton.edu/~mcdonald/examples/accel/butt_la-ur-96-1954.pdf

http://puhep1.princeton.edu/~mcdonald/examples/accel/momose_vacuum_47_1491_96.pdf

http://puhep1.princeton.edu/~mcdonald/examples/accel/lillard_jnm_278_277_00.pdf

http://puhep1.princeton.edu/~mcdonald/examples/accel/noji_jjim_66_1107_02.pdf

http://puhep1.princeton.edu/~mcdonald/examples/accel/maloy_targetry_05.pdf

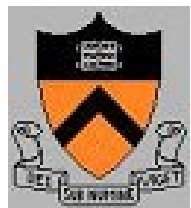
I found one paper that says tungsten carbide is fairly good in water:

http://puhep1.princeton.edu/~mcdonald/examples/accel/wentzel_jirmhm_15_81_97.pdf

Tungsten and tungsten carbide spheres are actually composites, with lower than maximal density for commercial grade. Tantalum spheres are available at full density.

Radiation damage to the compound WC may be an issue.

⇒ Tantalum may be the best high- Z material.



Shield Material Comparision

Material	Density (g/cm ³)	dE/Dx (min I) (MeV/(g/cm ²))	Figure of Merit	Z _{eff}
LH ₂	0.07	4.1	0.3	1
Graphite	2	1.74	3.5	6
Water	1	1.99	2.0	2
Graphite/water	1.6	1.81	2.9	8
Mercury	13.5	1.13	15.3	80
Pb/Bi eutectic	10.3	1.12	11.5	82
Ta spheres	16.6	1.15	19.1	73
Ta/water	10.4	1.18	12.3	65
Ta/Pb/Bi	14.1	1.14	16.1	75
Ta/mercury	15.4	1.14	17.6	75
W spheres	16(-18?)	1.15	18.4	74
W/water	10.0	1.18	11.8	65
W/Pb/Bi	13.7	1.14	15.6	75
W/mercury	15.0	1.14	17.1	75
WC spheres	14.5	1.21	17.5	60
WC/water	9.1	1.24	11.3	55
WC/mercury	14.1	1.18	16.6	65
WC/Pb/Bi	12.8	1.18	15.1	65

Comments:

Comparison assumes the density \times dE/dx is the relevant figure of merit.

Ta/mercury or Ta/Pb/Bi is best.

Pure mercury shield is very favorable.

Pure lead has properties similar to Pb/Bi

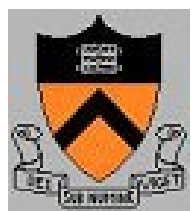
Pb liquid above 328° C.

Pb/Bi liquid above 128° C.

Ta/water still viable (equivalent to pure Pb/Bi).

Graphite/water shield must be very thick.

Z_{eff} for use in Geant/MARS.



Open Issues

Shield with high-Z material and liquid coolant is required.

Is a liquid-metal coolant acceptable? Pb, Pb/Bi, Hg?

If liquid-metal coolant not acceptable, probably must use low-Z solid target (and longer high-field solenoid).

If liquid-metal coolant is acceptable, then probably favorable to use liquid-metal target/beam dump.

For now, I consider the baseline to be liquid-metal target, beam dump and shield coolant.

Should the shield be pure liquid metal, or, say, Ta/liquid metal?

I believe that both of these options should be explored.

Option for water-cooled shield can be considered without (I think) major extra effort.

Solid-target option could be considered as part of water-cooled shield option.

Need greater effort on mechanical design of shield/beam dump (and magnets, iron plug, ...)

Need spec as to maximum allowable head load per meter in superconducting magnet from secondary particles.

Need coordinated effort on coolant flow (flow path, stagnant regions, required pressure...)

Opportunity exists for collaboration with Peles group at RPI, which studies heat transfer in microchannels: <http://www.rpi.edu/~pelesy/index.htm>

If water cooling, advantageous to use boiling (2-phase) flow; can this be controlled in our environment?

