Neutrino Factory Feasibility Study 2: Parameters and Tasks for Targetry and Capture

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Feasibility Study 2 Editors Meeting

(LBL)

`http://puhep1.princeton.edu/mumu/target/`

From *Initial Parameters for Study 2*

2.1 Proton Driver

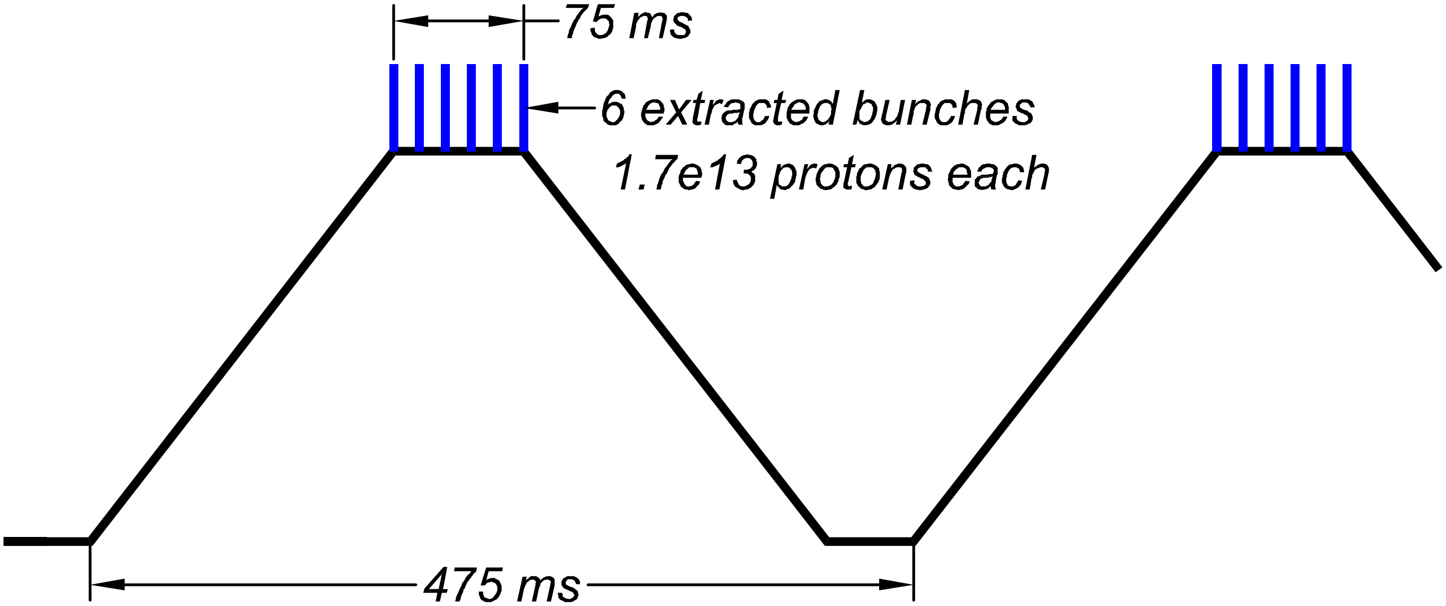
Energy	24	GeV
protons per bunch	$\approx 1.7\ \ 10^{13}$	
bunches per fill	6	
time between extracted bunches	≈ 20	ms
repetition rate	2.5	Hz
rms bunch length	≤ 3	ns
beam power	≥ 1	MW

Finite time between bunches is required for a number of reasons:

- To allow time to refill the RF cavities in the accelerating systems and avoid excessive beam loading;
- To avoid the need for multi pulsing of the induction linacs; and
- To allow the liquid target to be re-established after its assumed dispersal by the previous bunch. It is this requirement that sets the minimum spacing: The time required depends on the jet velocity and other parameters, and is not yet known. The number of 20 ms is a reasonable starting assumption. An even separation of bunches at 15 Hz would also be even better, but would require an accumulator ring.

The possibility of an average power greater than 1 MW, up to 1.5 MW should also be considered. This would correspond to the average power assumed in Feasibility Study 1.

Proposed Proton Driver Cycle



[Based on possible AGS performance.]

From *Initial Parameters for Study 2*, cont'd.

2.2 Target

material	mercury	
velocity	≈ 20	m/sec
length	30	cm
diameter	1	cm
angle to muon axis	100	mrad
displacement of front from axis	≈ 1	cm

A single proton bunch will heat the liquid to a temperature above its boiling point and generate substantial shock pressures. It is not believed that these will have significant adverse consequences, but, if it did, liquid lead/tin eutectic could be used. A graphite target (as used in study 1) could also be considered as a backup, but would reduce the neutrino intensity by a factor of 1.9 (see section 3.5).

To Be Done:

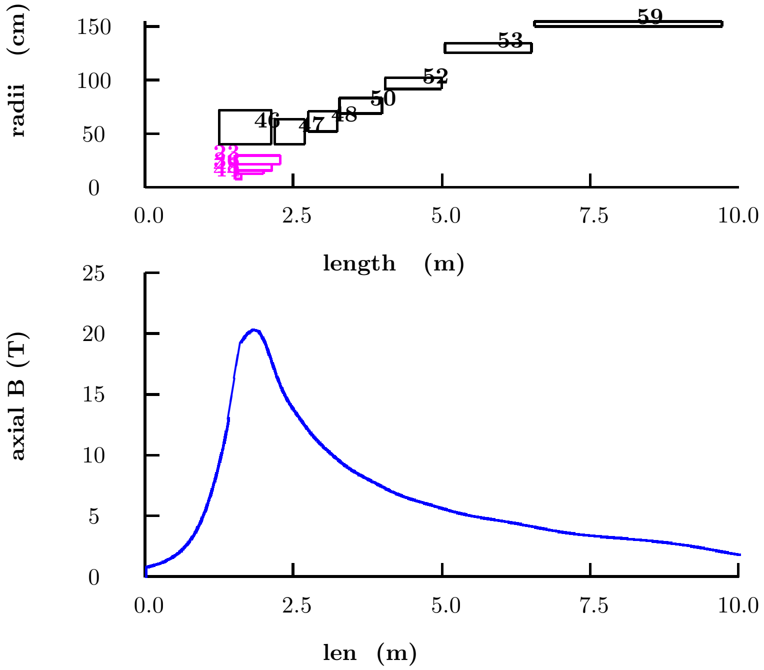
- Deflections and shape distortions of the liquid jet as it enters the magnetic field should be estimated (and later calculated when the programs became available), and the interaction of the proton beam with this distorted shape simulated.
- Production with lead/tin should be calculated and the optimum angle, length and radius determined for this case.

From *Initial Parameters for Study 2*, cont'd.

2.3 Capture and Matching Solenoids

The 20 T capture solenoid would be a hybrid, with copper (insert) and superconducting (outsert), magnet similar to that discussed in Feasibility Study 1. However, it is proposed here to use hollow copper conductor for the insert, rather than a Bitter style magnet in Study 1. The choice is aimed at achieving longer magnet life and avoiding any problems with highly irradiated water insulation. It is understood that the initial cost will be higher.

After the 20 T magnet, coils are designed to taper the axial field down slowly to 1.25 T over a distance of approximately 18 m. The form of the tapered field is approximately $B(z) \approx 20/(1 + k\, z)$. The final design will have to include space for the beam dump and shielding.



To Be Done:

- Design Beam dump and shielding, and modify coil designs to allow for them.

From *Initial Parameters for Study 2*, cont'd.

3.5.3 Target Material & Proton Energy

For comparison with Feasibility Study 1, we have run MARS/ICOOL with a carbon target (80 cm long, at 50 mrad) and 16 GeV proton energy. These are given below together with the Study 1 values.

	p energy	rms bunch length	μ/p	μ/p
	GeV	ns	15 mm	9.75
Mercury	24	3	0.20	.164
Carbon	16	3	.069	.057
Carbon (Study 1)	16	3		.018

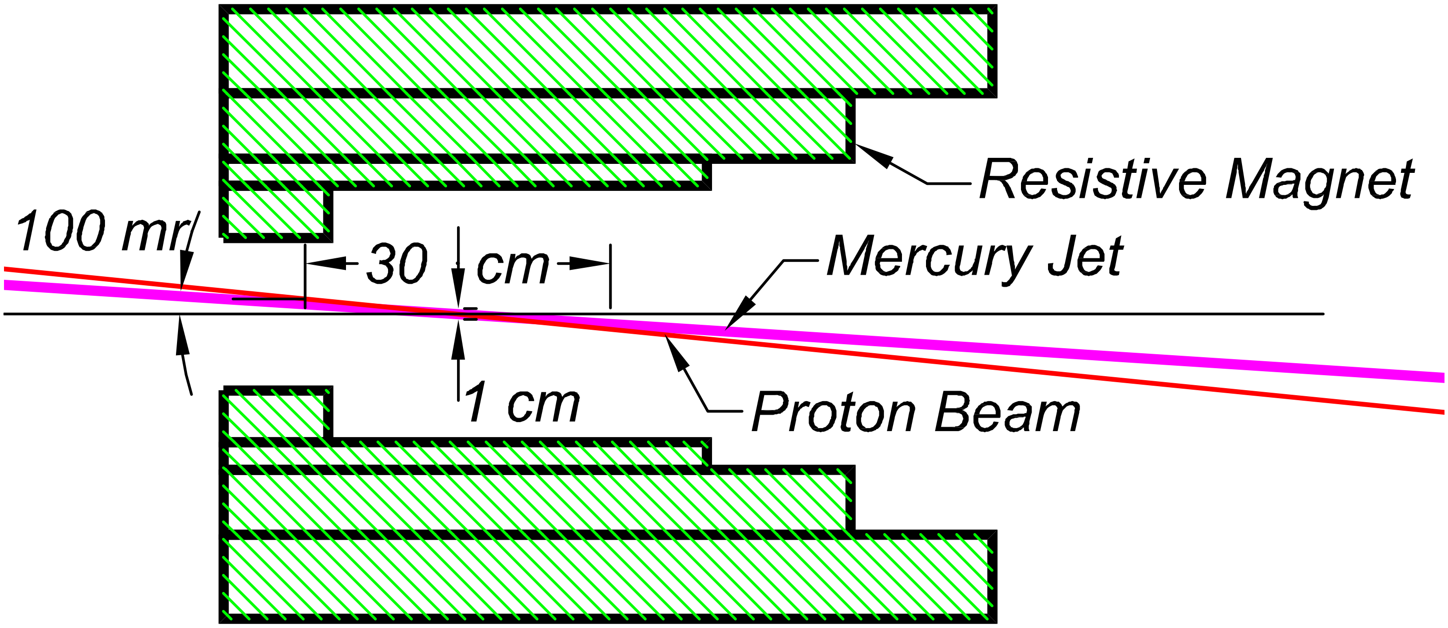
So the gain over Study 1 from the capture and cooling design improvements is 3.2 ×; the gain from the use of the mercury target is 1.9 ×; and from the use of a larger accelerator acceptance is 1.2 ×; for a total gain of 7.4 ×. It should be noted that other authors have also reported cooling schemes with efficiencies substantially greater than those in the Feasibility Study 1. It is believed, nevertheless, that the scheme proposed here has significant advantages.

Engineering and Simulation Tasks

Four Topics:

1. The target itself.
   - Baseline design: Study 2 Parameters document
   - Critical issue: Will the first of 6 beam pulses disrupt the whole mercury jet?
   - Engineering: ORNL (?)
   - Simulation:
     - Pion production: H. Kirk, N. Mokhov
     - Thermal hydraulics of beam-jet interaction: R. Samulyak, N. Simos
     - Magnetohydrodynamics of beam-magnet interaction: S. Kahn, R. Samulyak

The center of the proton beam enters the mercury jet at the upstream end of the nominal 30 cm long interaction region:



Mars Simulation Results of Hg Target

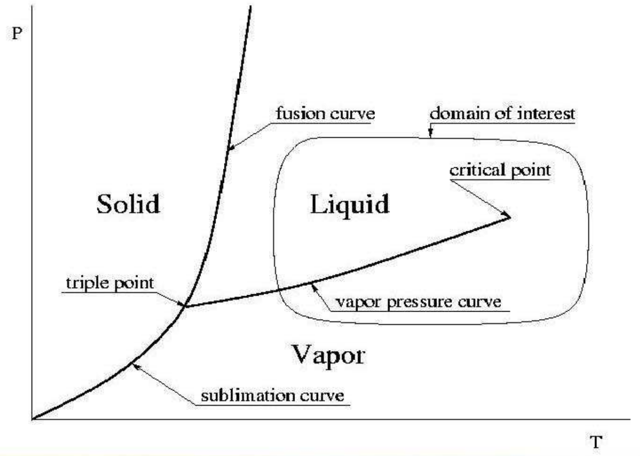
L=30cm; r=5mm; Beam Tilt= 100mrad

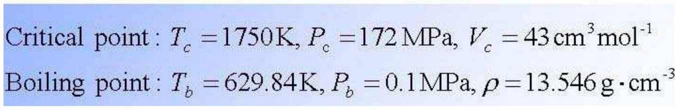
Pion/Proton crossing downstream plane of target

Target Tilt	133	100	67
π^-	1.098	1.134	1.091
π^+	1.106	1.151	1.117

Thermal Hydraulics

R. Samulyak, using the FRONTIER code:

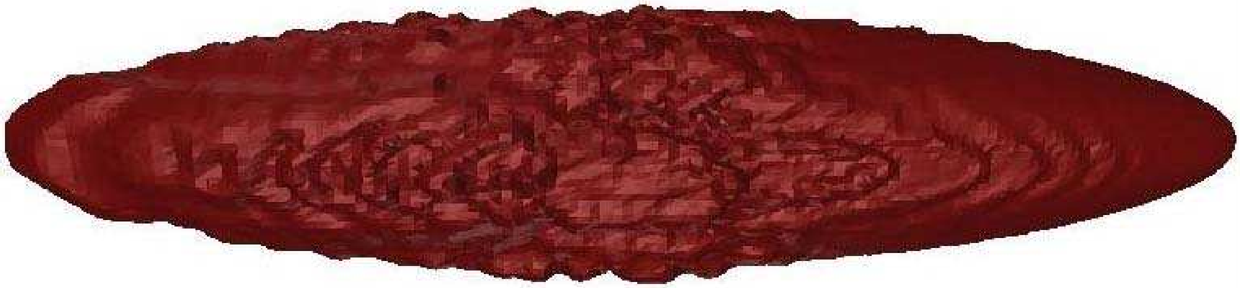



Critical point : $T_c = 1750\,\mathrm{K}$, $P_c = 172\,\mathrm{MPa}$, $V_c = 43\,\mathrm{cm}^3\mathrm{mol}^{-1}$

Boiling point : $T_b = 629.84\,\mathrm{K}$, $P_b = 0.1\,\mathrm{MPa}$, $\rho = 13.546\,\mathrm{g}\cdot\mathrm{cm}^{-3}$

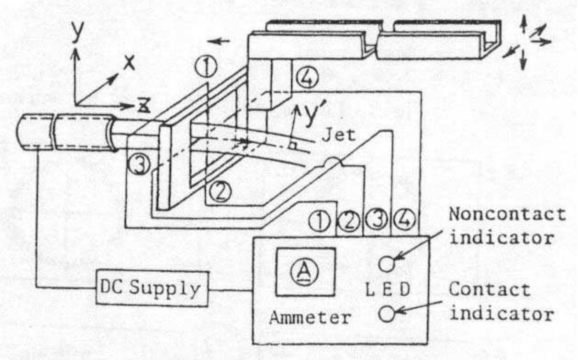
Beam + Hg jet (no magnetic field), $t = 0$:

Beam + Hg jet (no magnetic field), $t = 6\ \mu$s:

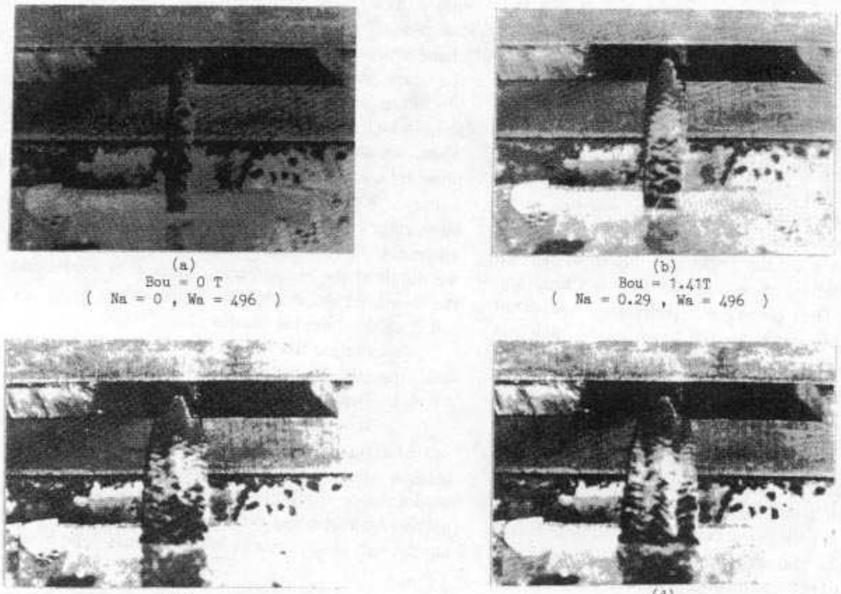


Magnetohydrodynamics being added to the code.

The Shape of a Liquid Metal Jet under a Non-uniform Magnetic Field



S. Oshima *et al.*, JSME Int. J. **30**, 437 (1987).

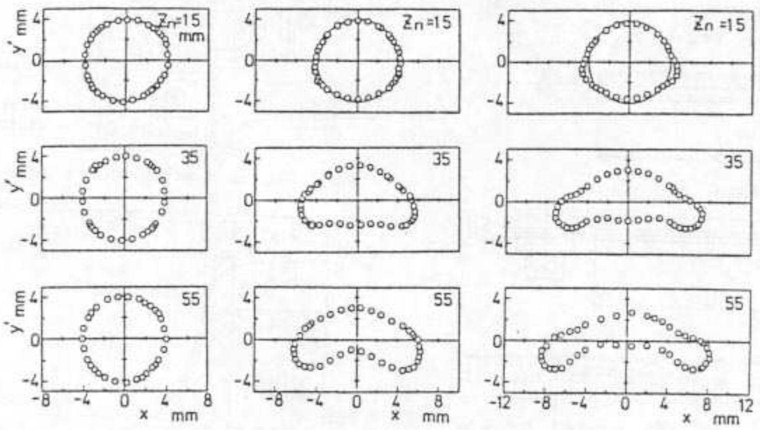

(a) Bou = 0 T (Na = 0 , Wa = 496)

(b) Bou = 1.41T (Na = 0.29 , Wa = 496)

(c) Bou = 1.88T (Na = 0.57 , Wa = 496)

(d) Bou = 2.02T (Na = 0.60 , Wa = 496)

Fig. 9 Photographs of the jet for various applied mag- netic field strengths



(a) Bou = 0 T (Na = 0 , Wa = 496)

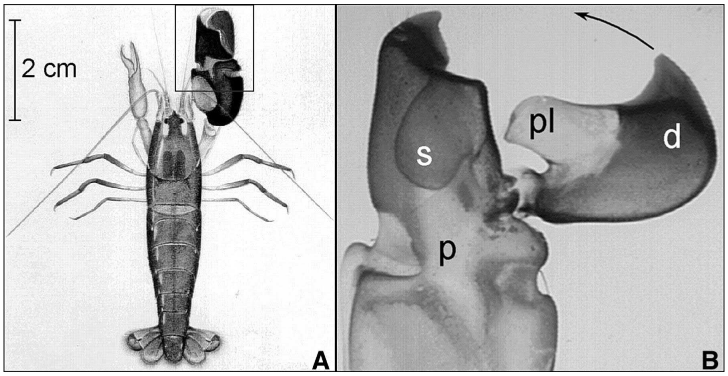
(b) Bou = 1.41 T (Na = 0.29 , Wa = 496)

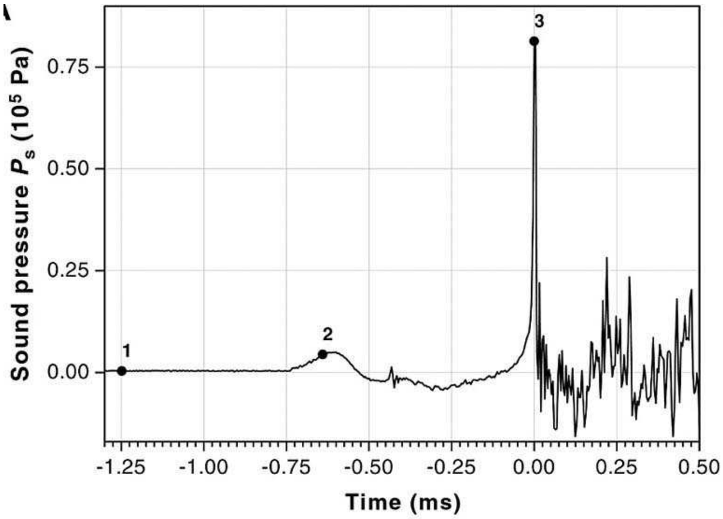
(c) Bou = 1.88 T (Na = 0.57 , Wa = 496)

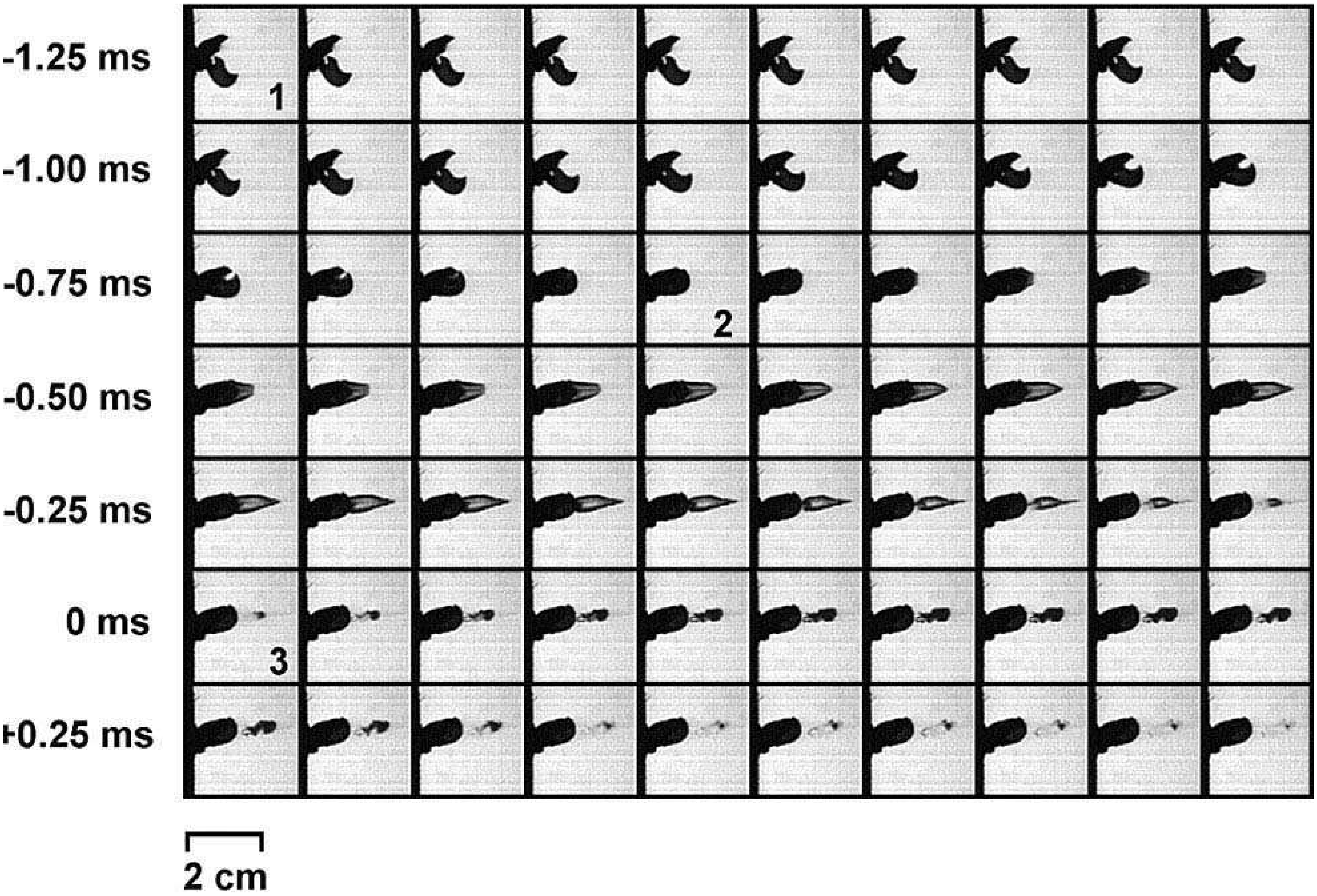
Fig. 10 Cross-sectional shape of the jet obtained by spot a electrode probe

How Snapping Shrimp Snap: Through Cavitating Bubbles

M. Versluis , Science **289**, 2114 (2000).





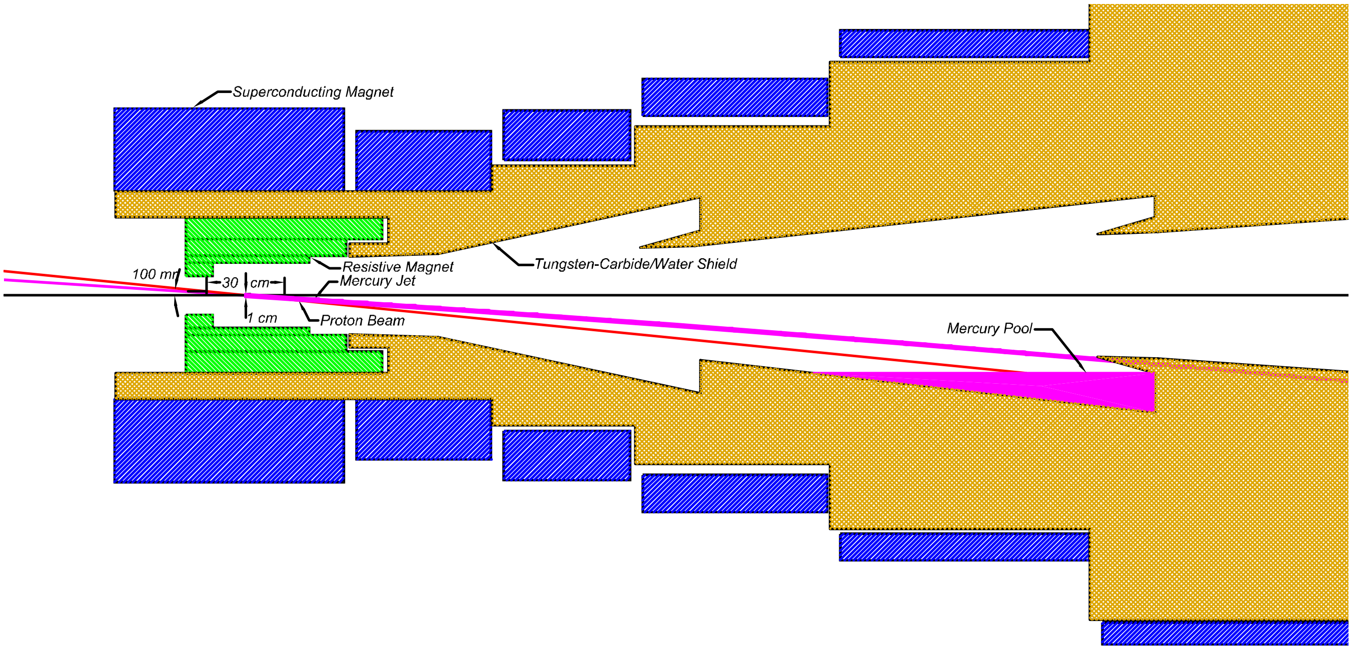


Engineering and Simulation Tasks, cont'd.

2. Beam Dump and Shielding

- Baseline design: I. Stumer
- Critical issues: Personnel safety;
  Radiation damage;
  Radionucleide activation.
- Engineering: ORNL (?)
- Simulation: H. Ludewig, N. Mokhov, I. Stumer

The proton beam is dumped, and the mercury jet collected, several meters downstream of the interaction region:



Engineering and Simulation Tasks, cont'd.

3. Mercury Handling

- Baseline design: SNS (ORNL) [+ ISOLDE (CERN)]
- Critical issues: 25 Atmosphere mercury loop;
  Radioactive byproducts
- Engineering: ORNL (?)
- Simulation: H. Ludewig, P. Spampinato

Mercury Handling at the SNS

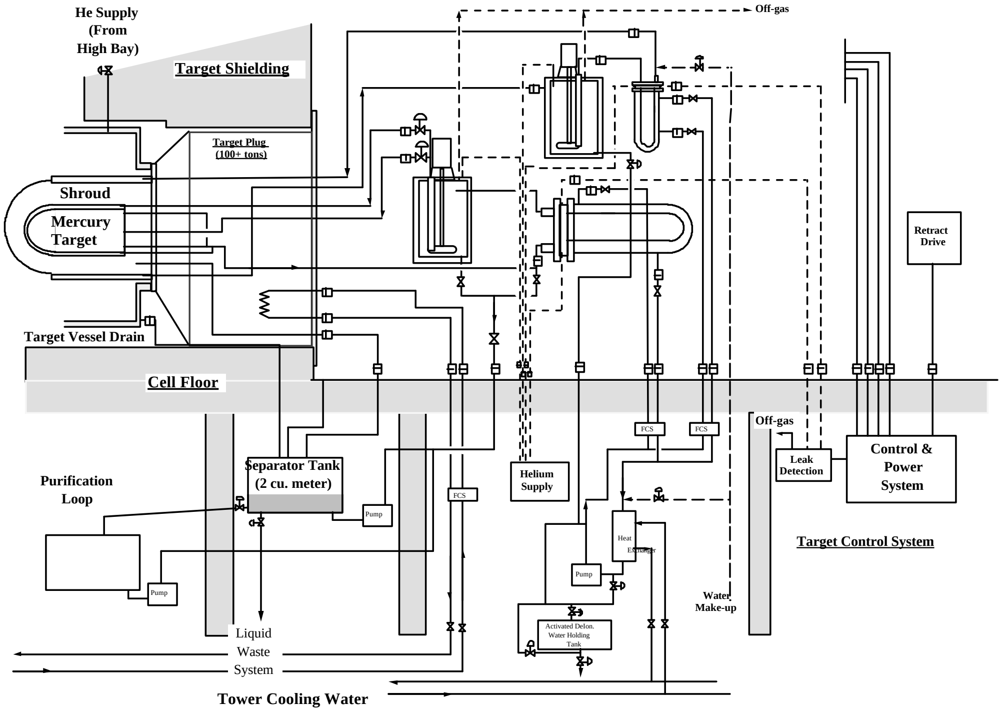


Fig. 5.3-1. Target system diagram.

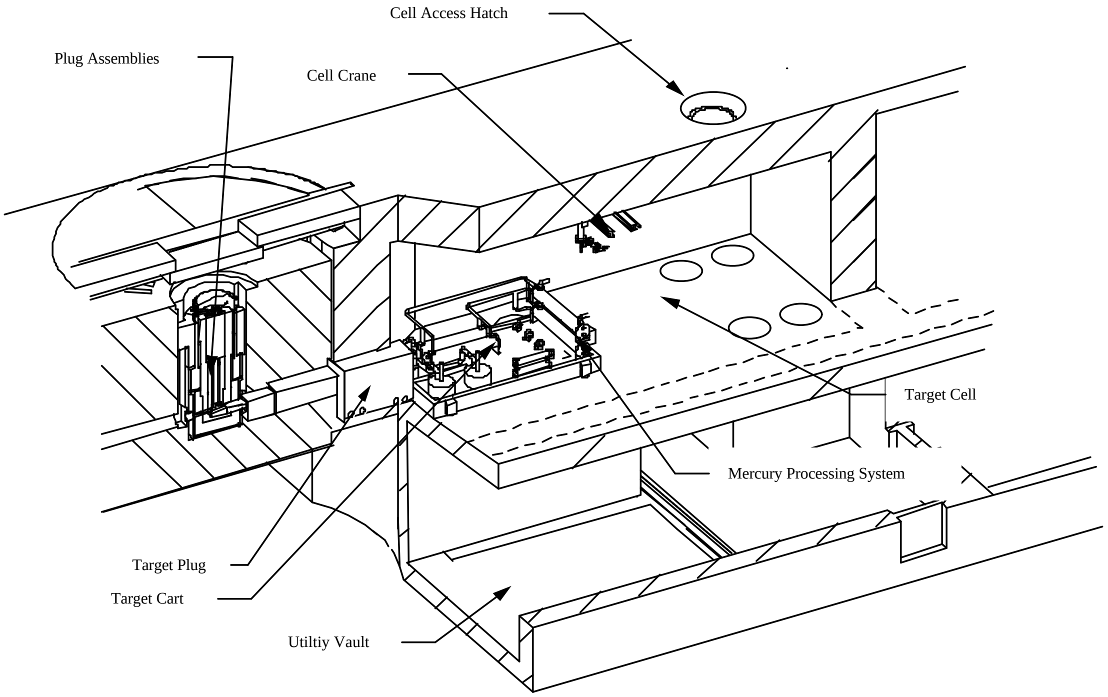
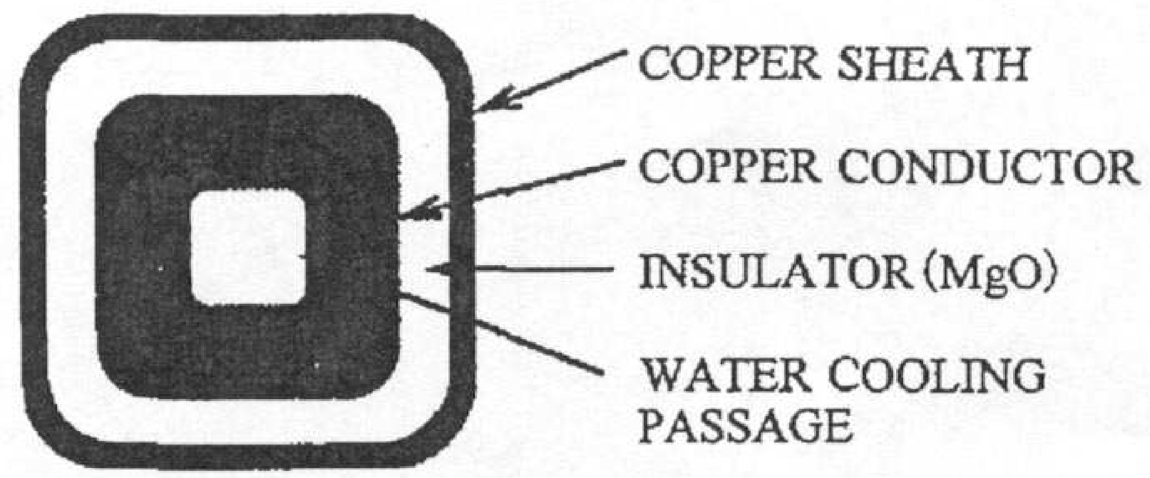


Fig. 5.3-2. Target system configuration.

Engineering and Simulation Tasks, cont'd.

4. Capture Solenoid

- Baseline design: Study 2 Parameters document
- Critical issue: Hollow conductor *vs.* Bitter coils in resistive magnet
- Engineering: NHMFL, B. Weggel
- Simulation: Y. Eyssa, B. Weggel



Development of Radiation-Resistant Magnets for the JHF Project

K.H. Tanaka, Y. Yamanoi, E. Kusano, M. Minakawa, H. Noumi, M. Ieiri, Y. Katoh, Y. Suzuki,
M. Takasaki, S. Tsukada, K. Yahata, Y. Saitoh and K. Katoh