The CNGS Targert - Explained

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Abstract

This note summarizes the information on the CNGS target design and and its operation conditions. The construction parameters and highlight information on the engineering studies performed at the design and construction phase are presented as a fast introduction to those interested. Last, in some critical areas like the thermal behavior of the target, calculations are included to adjust the estimates to the present operational conditions.

1 Introduction

The so-called **CNGS target** is in fact a large assembly with five target heads on a revolving magazine embedded in an iron shielding as shown in Figure 1. The reason for having such an assembly was twofold: first, to allow in-situ spares that could be exchanged remotely without intervention and beam time loss, and second, to give the possibility for using slightly different configurations (material, sizes, environment) as a result of the engineering studies giving different beam performance or material lifetime expectations. For the stringent conditions the CNGS target

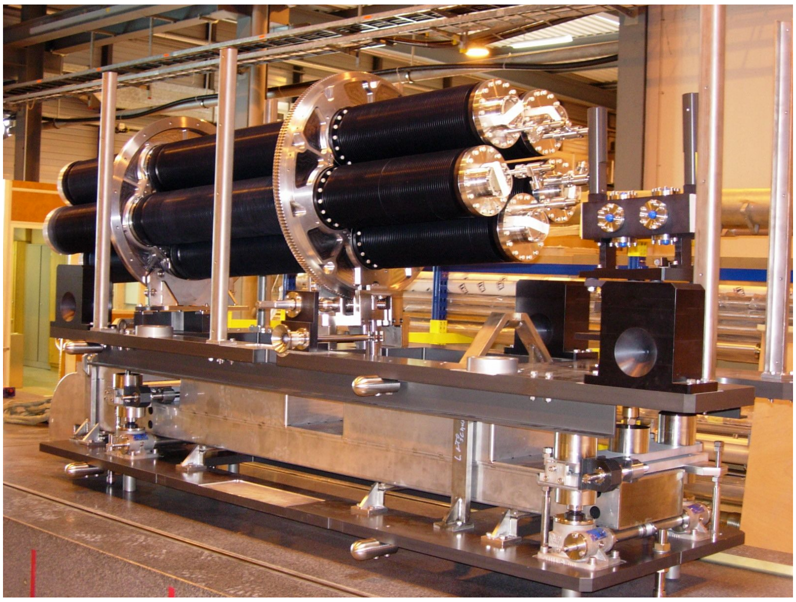

Figure 1: . Photo of the target magazine with the five target heads. A rotation mechanism located at the support table allows the remote exchange between the target heads.

had to operate, in particular for the ultimate beam power nominally close to 750 kW, the lifetime of the candidate material for the target heads is not well known. During the design studies, different options for the target head configuration and material were evaluated without clear preference among them. Each of the CNGS target heads is designed to receive the extracted primary beam from SPS at 400 GeV/c [2]. The primary beam parameters are summarized in Table 1.

Parameter	value
Beam energy	400 GeV/c
Beam cycle	6 sec
Bunch length	10.5 μsec
Extracions/cycle	2, 50 msec apart
Protons/extraction	2.0, 2.4, 3.5 $\times 10^{13}$
Protons/cycle	4.0, 4.8, 7.0 $\times 10^{13}$
Beam emittance	0.028 μm rad
No bunches/batch	2100
No batches/extraction	1
Bunch length	2 ns (4σ)
Bunch spacing	5 ns

Table 1: CNGS target and beam loading parameters. Proton beam parameters from ref [1]. The three values in the intensity correspond to : present, nominal and ultimate beam configurations from SPS. The beam emittance corresponds to nominal.

Each head consists of 13 carbon rods each 10 cm long. The first 8 rods are spaced 9 cm apart to allow the produced hadrons to escape and not reabsorbed in the target material. Also, the first two rods have a biggger diameter (5 mm instead of 4) as they are supposed to receive the maximum of the energy deposition from the beam impact. The total length of the target head assembly is 2 m, while the carbon material is 1.261 m. The details of the target head assembly are shown in Figure 2. The proton beam is focused at the position 839.4 m from the center of

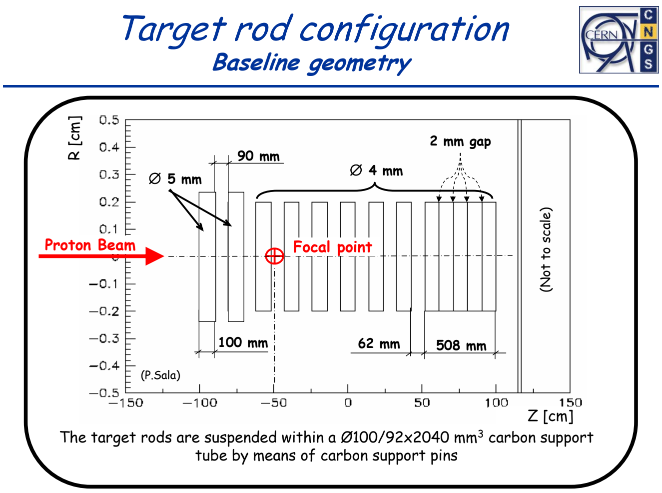

Figure 2: Left: drawing of the target head baseline geometry showing also the beam focus point. Right: photo of one of the target heads. The graphite rods are visible inside the carbon-fiber supporting structure.

QDA41910 quadrupole of the TT41 line which corresponds to 50 cm inside the target head (see Figure 2). For the nominal beam, the spot sized at the target has a sigma of 0.53 mm in both planes, and a divergence of 0.050(0.030) mrad in the horizontal(vertical) plane. During operation, effort is made to maintain the beam spot size at the target constant with intensity, but small variations can be observed.

From the engineering studies, each of the target heads installed can survive the full approved CNGS physics program, i.e. to 2.2×10^{20} protons on target. The configuration for each of the five target heads is shown in Table 2 for the installed and spare target magazine. So far CNGS operates with the same target head - head # 1- which at the end of the 2011 physics run has received 13.5×10^{19} protons operating to an average of 75% of its nominal power and about 80% of its nominal beam intensity, without any sign of performance degradation.

Head	**Geometry**	**Gas**	**Carbon Material**
1st target unit			
1	baseline	Helium	Graphite - Graphite 2020PT by Carbone Lorraine
2	baseline	Helium	Sintered carbon - Sintered Carbon SC24 by Sintek Keramik
3	baseline	Helium	C-C composite - Aerolor A035 by Carbone Lorraine
4	baseline	vacuum	C-C composite - Aerolor A035 by Carbone Lorraine
5	Ø5 mm rods	Helium	"safe" Graphite - Graphite 2020PT by Carbone Lorraine
2nd (spare) target unit			
1	baseline	Helium	Graphite - Graphite 2020PT by Carbone Lorraine
2	baseline	Helium	Sintered carbon - Sintered Carbon SC24 by Sintek Keramik
3	baseline	Helium	C-C composite - Aerolor A035 by Carbone Lorraine
4	baseline	vacuum	Graphite - Graphite 2020PT by Carbone Lorraine
5	Ø5 mm rods	Helium	"safe" Graphite - Graphite 2020PT by Carbone Lorraine

Table 2: The CNGS target head configuration. Target unit No.1 of the first target unit is the one in use for CNGS since 2006.

The basic physical properties for the target materials are summarized in Table 3.

Properties			**2020PT**	**SC24**	**A035**
ρ	@RT	[g/cm^3]	1.76	1.87	1.75
c_p	@100 deg-C	[J/g/K]	0.97	0.94	*0.9*
α	@100 deg-C	[μm/m/K]	3.6	6.4	$\mathit{2}_{\parallel}$ / $\mathit{3}_{\perp}$
k	@100 deg-C	[W/m/K]	88.4	55.6	$\mathit{200}_{\parallel}$ / $\mathit{150}_{\perp}$
E	@RT	[GPa]	9.3	12.4	$\mathit{15}_{\perp}$
ν	@ RT	[-]	0.03	0.30	*0.30*
σ_u	@RT	[MPa]	29.1 ± 0.9	34.8 ± 4.6	$\mathit{40}_{\parallel}$ / $\mathit{20}_{\perp}$

Table 3: CNGS target head material properties. Values are from measurements, while those in italic are provided by the manufacturer of the C-C composite [**?**].

2 Energy deposition and thermal load on the target rods

The energy density (dE/dV (GeV/cm^3)) deposited in the target rods has been calculated using FLUKA and shown in Figure 3 [4]. In the calculations a carbon material density of 1.77 g/cm^3 is used.

The radial and longitudinal profiles for the energy deposition in teh target head rods is shown in Figure 4. As can be seen, in each rod the deposited energy peaks at its end. As the target is thin, the energy deposition profile maps to the meson production.

For the ultimate beam intensity and for 100% duty cycle, the generated power in the target rods corresponds to a maximum power of 144 kW in the second rod as shown in Figure 5. In the present running conditions the maximum power is limited to about half of that assuming 100%

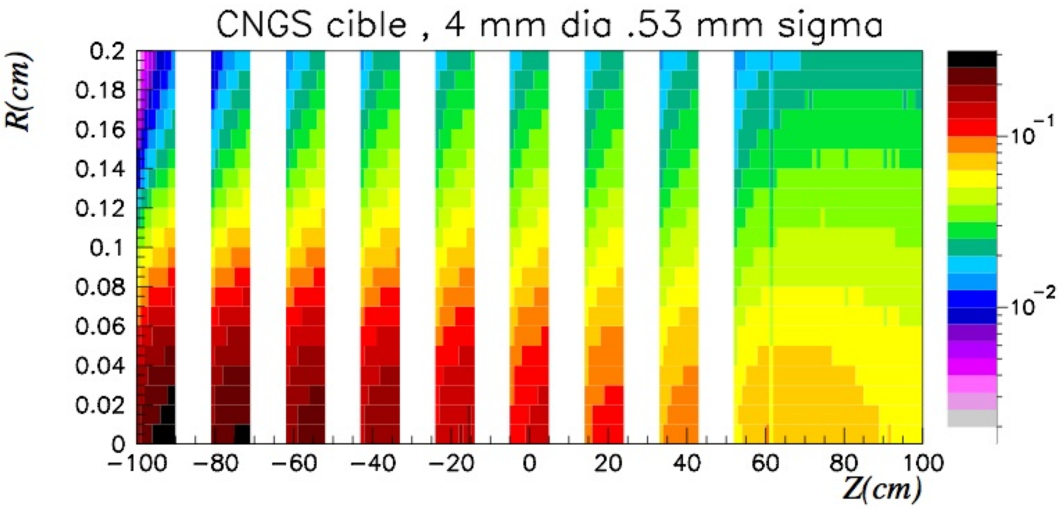

Figure 3: The energy deposited in the target rods per incident proton and for the nominal beam sigma of 0.53 mm. FLUKA simulation resutls from [2].

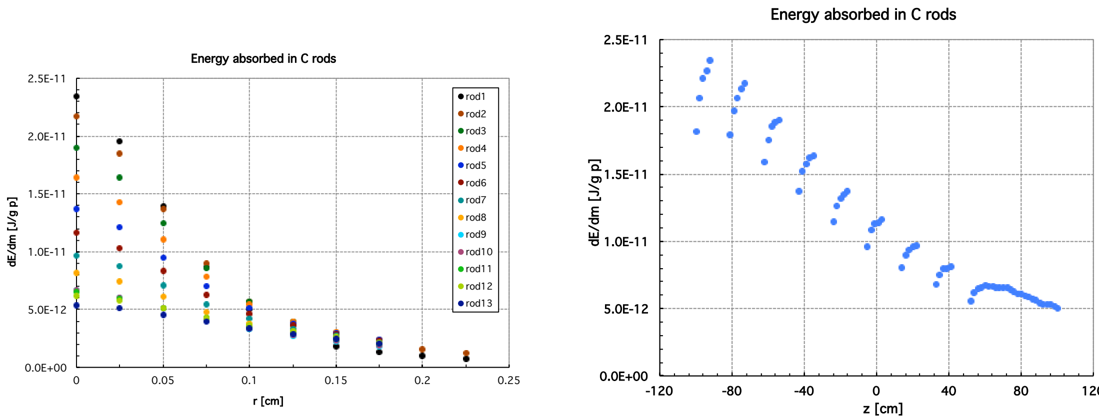

Figure 4: The energy deposited in the target rods per incident proton and for the nominal beam sigma of 0.53 mm. Left: radial distribution, right: z distribution.

duty cycle, while in reality is must less as the CNGS beam operates close to an average of 70% of duty cycle due to beam sharing with other SPS users.

The graphite rods of the target are supported using a C-C composite structure and the whole assembly is placed inside an Al tube as shown in Figure 6. The Al tube is leak tight, and is filled with He gas at slight under-pressure at room temperature. The power generated in the target rods is evacuated by radiation and convection through the Al external tube that is kept at constant temperature via an external air mass flow that is blown from underneath the target unit assembly (external cooling). The external cooling is designed such to maintain the Al tube at 313 K when operating in the ultimate beam conditions. In the present running with lower beam intensities, the smaller deposited power in the target is somewhat compensated by the lower heat transfer due to radiation, however it is generally expected the temperature in the outer Al cylinder will be lower.

From the energy deposition in the target rods, the temperature can be estimated using the for-

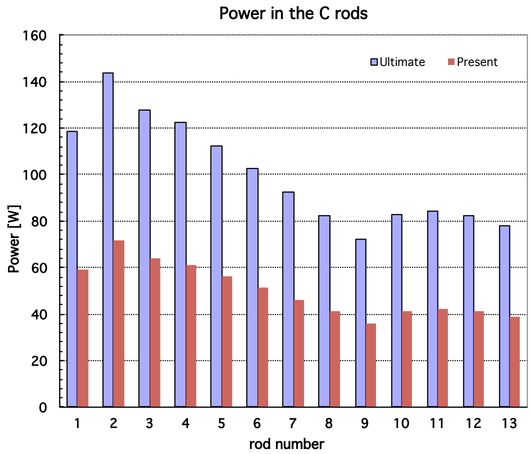

Figure 5: The beam induced power distribution in the target rods for the ultimate and present operational conditions. The scaling is done only for the beam intensity, assuming in both cases 100% duty cycle, i.e. beam every 6 s.

Rod	$<\Delta T>$ [K/pot]	$<\Delta T>$ [K/pulse]
1	$1.50E-11$	524.0
2	$1.42E-11$	496.0
3	$1.26E-11$	440.0
4	$1.08E-11$	378.0
5	$9.03E-12$	316.0
6	$7.66E-12$	268.0
7	$6.39E-12$	224.0
8	$5.38E-12$	188.0
9	$4.40E-12$	154.0
10	$4.61E-12$	161.0
11	$4.40E-12$	154.0
12	$4.01E-12$	140.0
13	$3.66E-12$	128.0

Table 4: Estimates of the average temperature increase per rod at the impact of the 400 GeV/c protons. The average temperature increase is calculated using the current operating beam intensity of $3.50E+13$ protons per pulse.

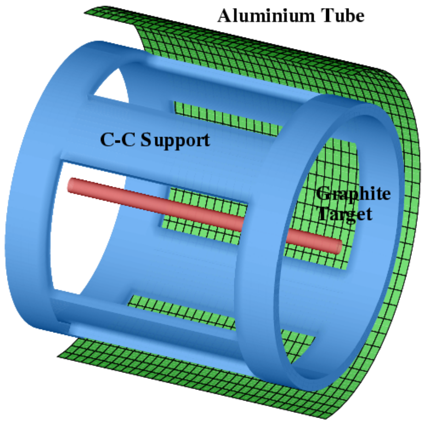

Figure 6: View of the target assembly. Only one rod is shown, the tube is extended ot the full length of the target (13 rods) and is completed with upstream and downsteram Be windows.

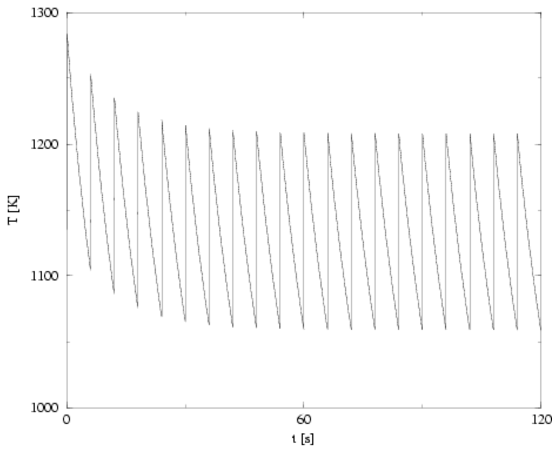

Figure 7: The time evolution of the surface temperature of the target rods. The calculation is done for the ultimate intensity of CNGS beam and at maximum beam power (i.e. continuous 6 s cycles).

mula:

$$T = \frac{dE/dV}{\rho C_p}, \tag{1}$$

where dE/dV is the deposited energy in (J/cm^3), ρ the density in (g/cm^3) and C$_p$ the specific heat in (J/g/K).

With the first beam pulses, the temperature in the target rods increases fast, but then the radiation cooling starts and finally and the rods arrive to a thermal equilibrium after few shots. Once in equilibrium, at each beam pulse the temperature of the rods oscillates to a maximum of 700 degK as shown in Figure 7. For the ultimate beam conditions the equilibrium is reached after about 10 beam pulses, while in the present operation the lower beam intensity and therefore the lower generated power is compensated by the less effective radiation cooling but in general is expected the target reaches equilibrium temperature after few minutes.

Using the data from Figure 4 and equation 1 the temperature increase for each rod per incident proton can be estimated, the results shown in Table 4. For the calculation the C_p value of 1.429 J/gK is used that is measured at 1400-degK, and the last column corresponds to the temperature increase per pulse in the present running conditions, i.e. 3.5E13 protons/pulse.

The average temperature increase per pulse at the present beam conditions is 275-degK and the maximum is 524-degK for the first rod. In Table 5 the variation of the graphite density with temperature is shown. Assuming the target head rods are free to dynamically expand in volume, the temperature increase in each pulse could be translated to a density variation. For the first rod that has the maximum temperature variation this corresponds to about 1%, while the average temperature to 0.6%.

T [K]	ρ**[kg/m3]**
20	1795.342978
50	1794.649974
80	1793.957328
120	1793.036331
200	1791.177762
350	1787.428477
500	1783.422541
700	1777.66646
1000	1767.901853

Table 5: The temperature dependence of the graphite density.

Should be noted however that such calculations are intrinsically not correct as the energy deposition in each rod is calculated using a constant density! In reality what happens is that as the target heats up and its density varies, the proton beam penetrates deeper in the target material. For an infinite long target such an effect will have minimal impact to the particle production. For the CNGS target is almost the case, however the exact answer requires a dynamic analysis for the time evolution of the energy deposition within the beam pulse and the temperature variation of the target rods.

References

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