Graphite Rod Cooled by Longitudinal Flow of 10-Atmosphere Helium Gas

Bob Weggel Magnet Optimization Research Engineering (M.O.R.E.), LLC 3/17/2014

Figure 1 shows the power P(z) deposited in 2-cm slices of a graphite rod of density = 1.8 g/cm^3 by a 4-MW, 6.75-GeV proton beam. The integrated heating is 111 kW, or 28 kW per megawatt of beam power (grey curve, evaluated at downstream end of rod, z = 40 cm). The maximum heating per unit length is 4.6 KW per 2-cm slice, which equates to 575 W/cm per megawatt of beam power. An 8th-order polynomial (black curve) fits the data. The polynomial for dP/dz, when converted to W/cm at one megawatt of beam power, is: $352 - 8.05\,z + 0.0525\,z^2 + 7.95\text{e-}4\,z^3 - 8.7\text{e-}6\,z^4 - 1.04\text{e-}6\,z^5 - 3.29\text{e-}8\,z^6 + 1.52\text{e-}9\,z^7 - 1.14\text{e-}11\,z^8$.

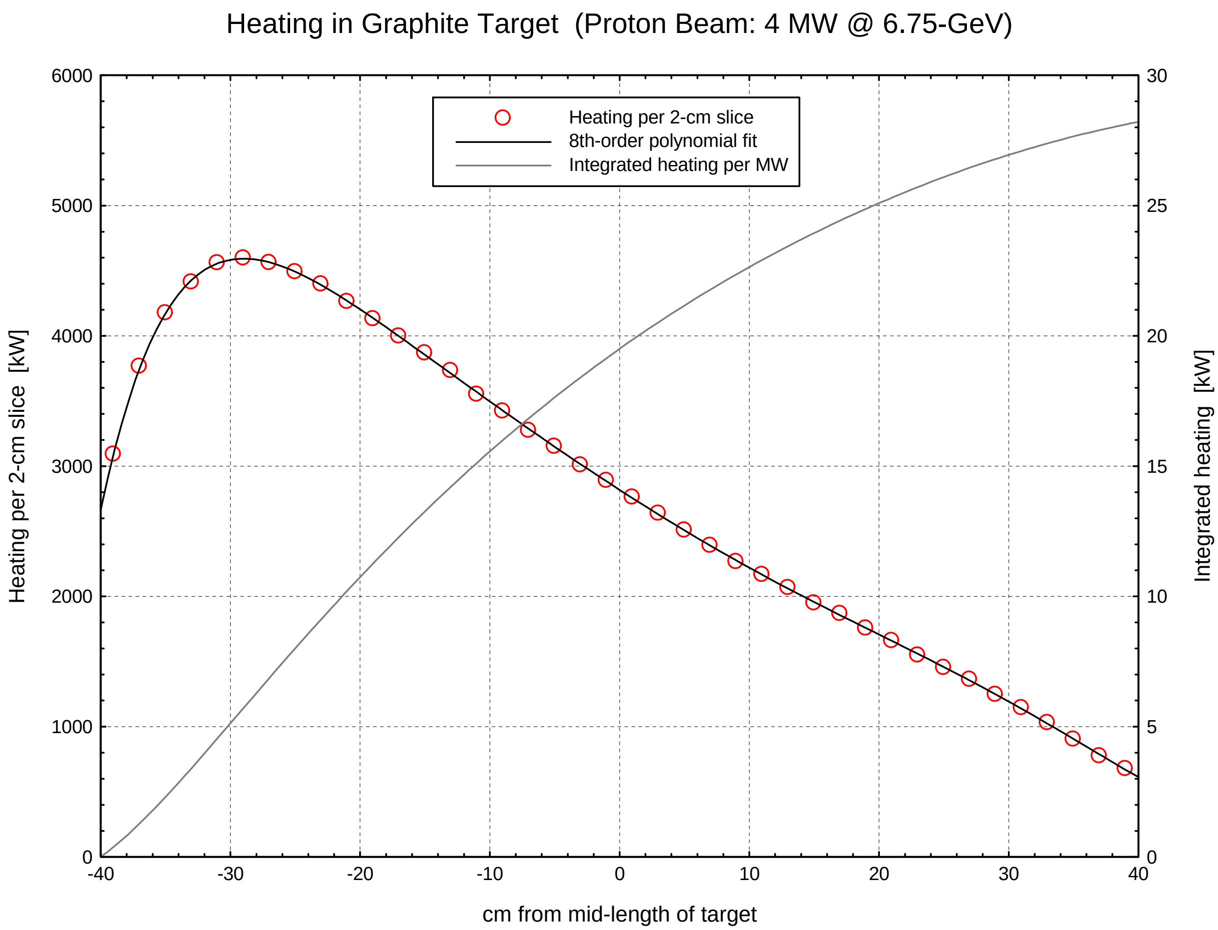

Fig. 1. Heating in 2-cm slices of 1.8 g/cm^3-graphite rod by 4-MW, 6.75-GeV proton beam.

If the heating density w_v as a function of radius is Gaussian, $w_0 e^{-cr^2}$, with c = 25 cm^{-2}, then the hot-spot (thermal-gradient) temperature rise within a target of unit radius and unit thermal conductivity is as in Fig. 2.

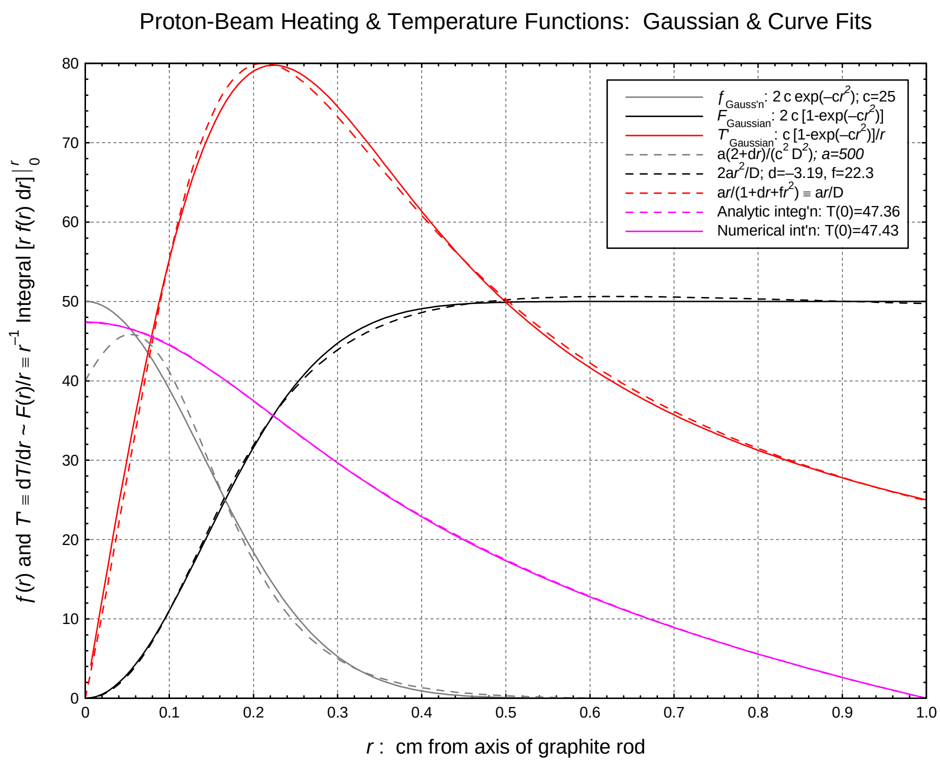

Fig. 2. Proton-beam heating density $f(r)$ [grey curves], integrated heating $F(r) = 2\pi \int_0^r f(r) r dr$ [black], $T'(r) = \frac{F(r)}{2\pi k r}$, where k is the thermal conductivity [red], and $\Delta T(r) = \int_r^1 T'\, dr$ [pink] in rod of unit radius and thermal conductivity. Solid curves are for a Gaussian heating density $2ce^{-cr^2}$; dashed curves are fitting functions. The dashed pink curve, obtained by analytic integration of its red mate, involves logarithms and arctangents.

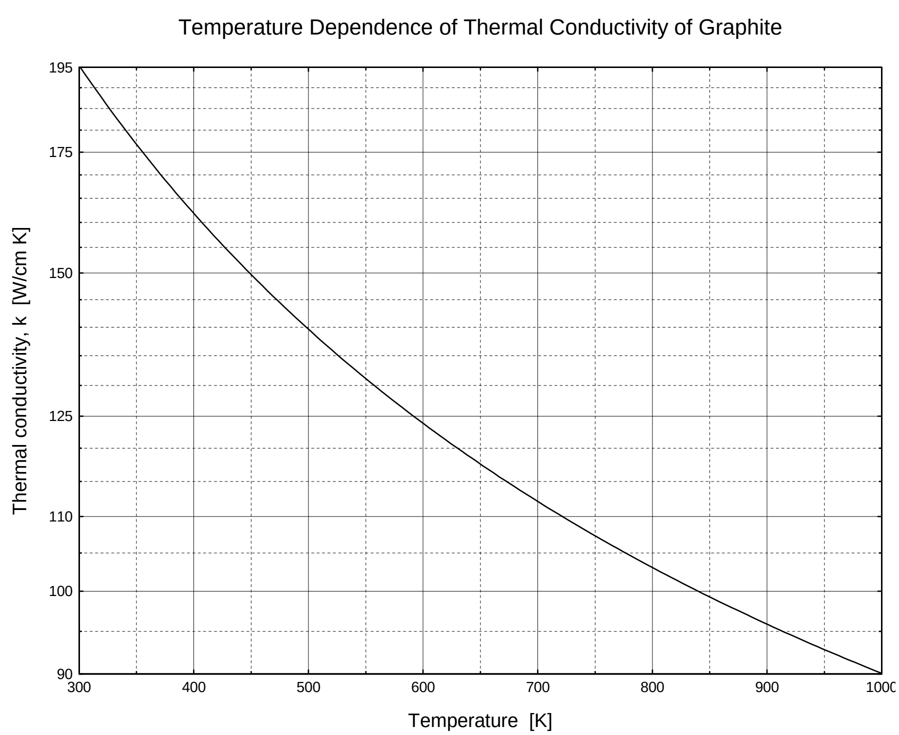

Fig. 3. Temperature dependence of thermal conductivity of graphite: $k = 54.73 \div \left[1.077 - e^{-(T/1322)}\right]$ W/cm·K.

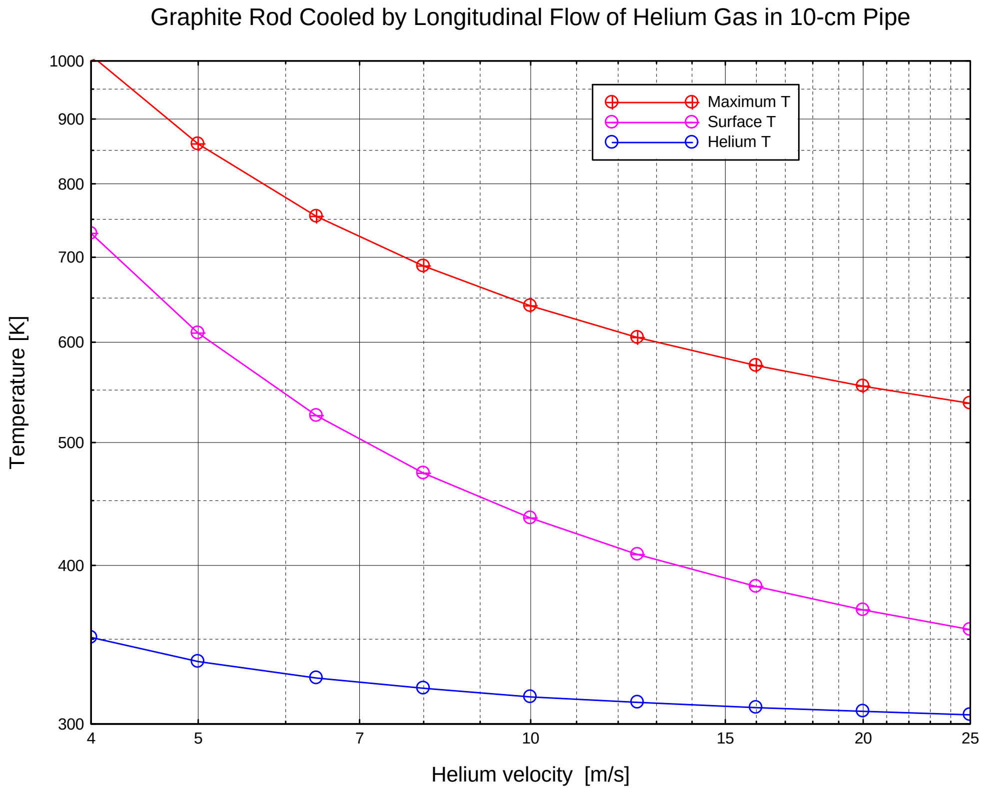

Fig. 4. Bulk, surface and maximum temperature at z = −25 cm (15 cm from upstream end) along graphite rod of 1-cm radius heated as in Figs.1 & 2 and with thermal conductivity as in Fig. 3. Helium pressure is 10 atmospheres; inlet temperature is 300 K. Bulk temperature of helium assumes perfect mixing within pipe of 10-cm I.D.

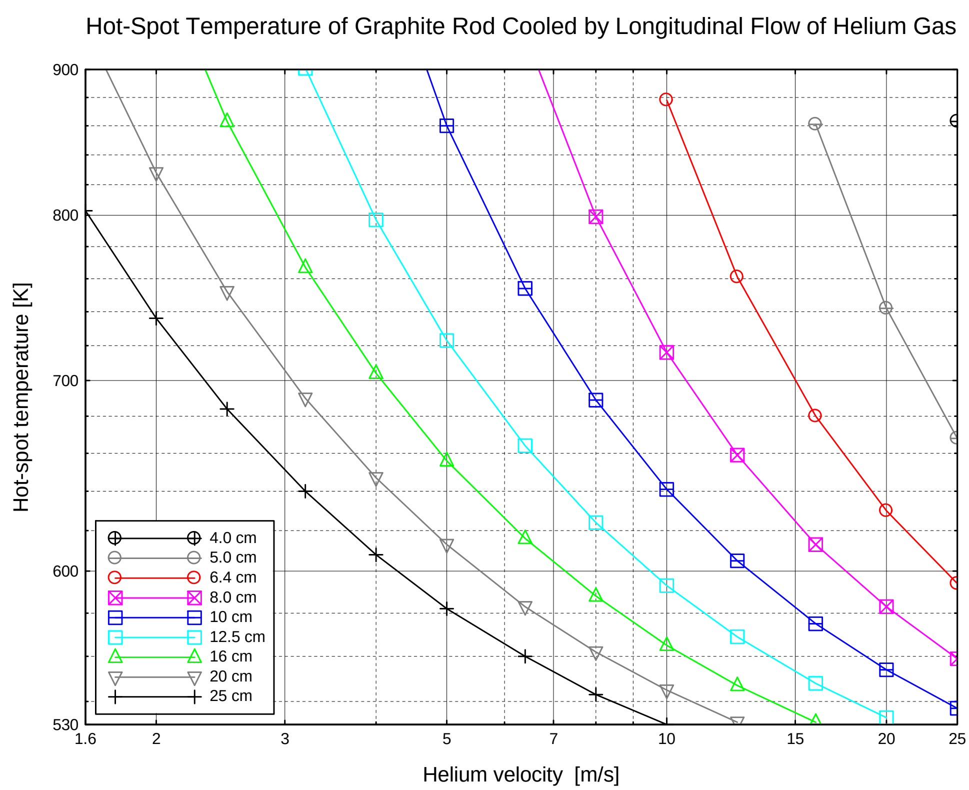

Fig. 5. Hot-spot temperature (as in Fig. 4) vs. helium-pipe inner diameter from 4 cm to 25 cm.