Appendix A

Baseline cooling requirements for the multislab 10 Hz amplifier

The two options below are considered for

a) Nominally 100 J output pulses (“Mercury-class” system)
b) Nominally 500 J output pulses (“kilojoule-class” system)

Note: baseline configuration = suggested set of starting parameters for the simulations.

1. Geometry of the amplifier head

The geometry of the amplifier head in both cases is considered similar to Mercury (LLNL). It is assumed that the flow will be globally laminar between the slabs. The laminar flow between the slabs is ensured by aerodynamic vanes; their shape is not discussed here. The shape of the vanes should be suggested only *after* numerical optimization of all other parameters.

The total thickness of the amplifying medium in both cases a) and b) is 64 mmm. The active laser medium is Yb doped YAG ceramics (lasing wavelength 1.03 μm) supported by stainless steel mounts. These mounts can be used to assist carrying out the dissipated heat from the YAG ceramics.

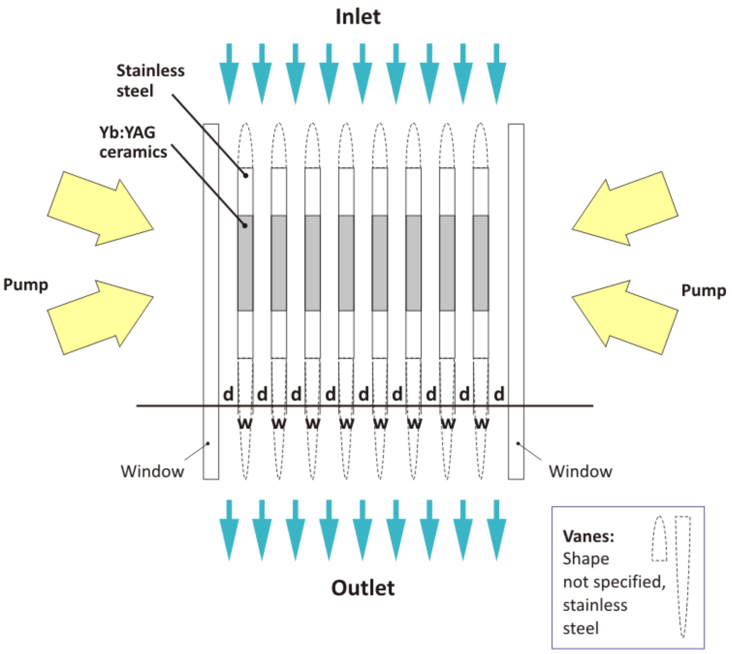

Figure 1: Longitudinal schematic of the cryogenic amplifier head. Total thickness of the lasing medium=64 mm. In the baseline configuration number of slabs=8, d=2 mm, w=8 mm, for both cases a) and b).

After running the baseline simulation, the calculations should look at varying the thickness of the slabs (looking e.g. at two cases, d=5 mm and d=10 mm) while keeping the total thickness of the lasing medium=64 mm. The simulations should also look at the effect of varying the width of the He channel with respect to the thermal balance and on laminarity of the flow.

The transverse section of the amplifier is in Figure 2. The active medium is square and the pumped region (beam size) for the two investigated cases is

a) 5x5 cm
b) 10x10 cm

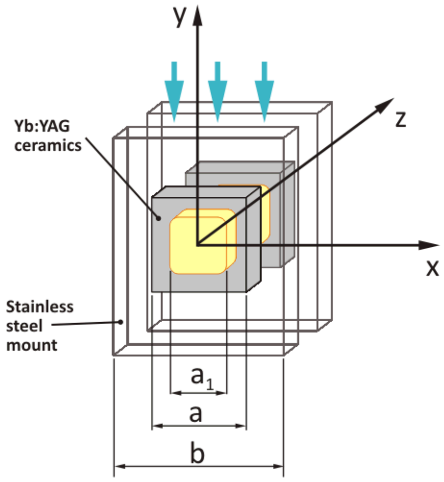

Figure 2: Transverse schematic of the cryogenic amplifier head. The dimensions are for the configuration a) a_1=5 cm, a=7.5 cm, and for configuration b) a_1=10 cm, a=12.5 cm. In the baseline configuration, the width b of the stainless steel mounts is b=2a.

Maximal temperature difference across any direction in the plane (x,y), <u>in one slab</u> is:

$\Delta T\ (x,y) = 3$ K

Note 1: ΔT of 6 K may still be tolerable, but would likely require using correction optics.

Note 2: Temperature gradients in the slabs along the longitudinal z-direction are unessential (provided that they do not induce material stress that would generate birefringence).

Note 3: Thermal properties of materials:

1. Thermal conductivity of YAG ceramics:
no data found yet in literature regarding dependency on temperature, but we think that the simulations can consider 18 $Wm^{-1}K^{-1}$ as the baseline value.
2. Thermal conductivity & heat capacity of He at cryogenic temperatures (150 to 180 K): only few data found in the literature - <u>it will be needed to make a set of reliable measurements</u>; as for EOS, cryogenic He can be considered, with sufficient degree of accuracy, as ideal gas in the simulations.
3. Thermal conductivity of stainless steel (and/or other materials): available.

<u>2. Parameters of the pumping pulses (from laser diode modules)</u>

The simulations should assume as if the pump were DC (the length of 1 ms of the pump pulses being short), i.e. uniform dissipated thermic heat in time.

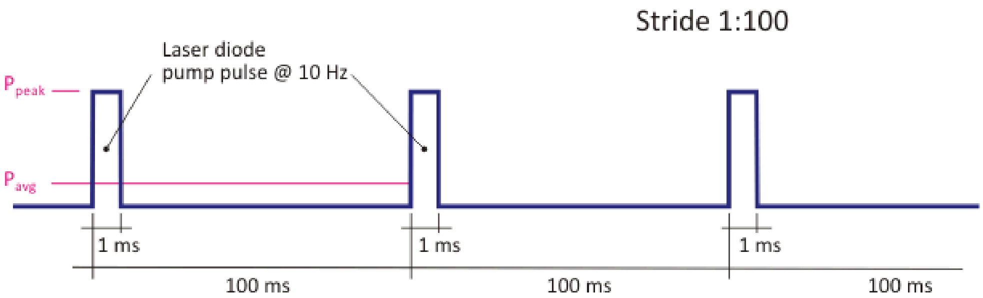

Figure 3: Time diagram of the pump (for 10 Hz and 1 ms pump pulses, $P_{average} = P_{peak}/100$).

The design of the amplifiers assumes that the pump light (wavelength ~940 mm) fluence is 5 J/cm^2 (i.e., given the 1-ms pump pulse duration, the peak intensity 5 kW/cm^2). As mentioned above, for 10 Hz repetition rate and for 1 ms duration of the pump pulses, the average power = peak power /100).

The simulations should assume that pump (hence the source of the thermic heat) is delivered with perfect uniformity across the active medium (plane x-y).

We conservatively assume that the efficiency of conversion from the diode pumping light (~940 nm) to the laser light (1031 nm) is 30% -> <u>70% of the pump light is dissipated into thermal heat</u>.

The total pump power and the dissipated power in the YAG ceramics for the two investigated cases of the (a) 100 J and (b) 500 J lasers are:

a) Pump power (average) = 3.3 kW, dissipated power (average) = 2.3 kW
b) Pump power (average) = 16.7 kW, dissipated power (average) = 11.7 kW

It is assumed that He absorbs no pump light.

In the axial direction along the z-axis, the profile of the absorbed pump light, i.e. the source of the thermic heat, has a general profile

$$P_{dissipated} = A\left[\exp(-\alpha z) + \exp(+(\alpha(z-L))\right]$$

where

A … constant (dissipated heat in Wcm^{-3}cm^{-1})

α = 0.2 (baseline value)

z … axial z-distance in the amplifying medium (YAG ceramics), see Figure 2.

L = 6.4 cm (total length of the amplifying medium)

In both cases of the (a) 100 J and (b) 500 J lasers, the dissipated heat is ~ 14.4 Wcm^{-3}.

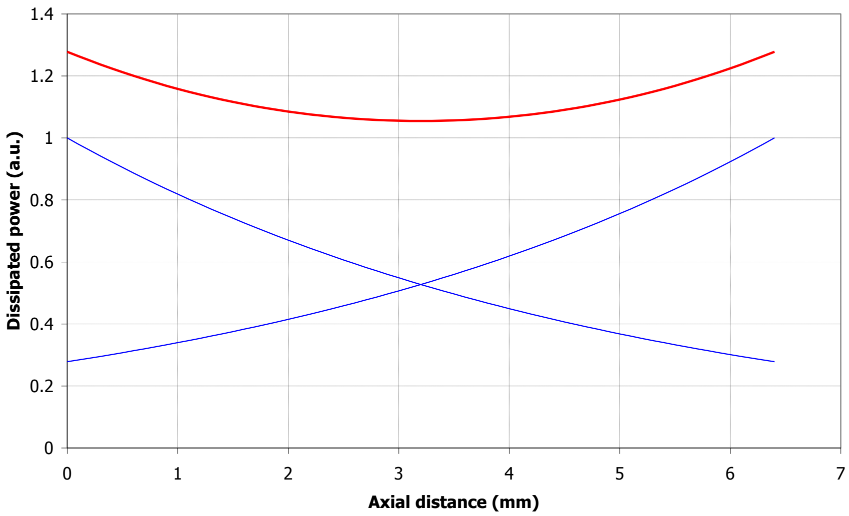

Figure 4: Red curve: longitudinal profile of the dissipated heat (in blue is shown dissipated heat due to the pump light coming from each side). The curve is in relative units, without the constant A (see the formula above).

3. Parameters of the helium flow

The baseline parameters of the cooling medium flow are similar to those at Mercury (LLNL) for both cases of the (a) 100 J and (b) 500 J lasers are:

Inlet temperature	175 K
Inlet pressure	4 atm
Inlet velocity	0.1 Mach

As mentioned above, helium can be considered as ideal gas for the purpose of the simulations.

The outlet helium temperature and pressure are free parameters.

4. Parameters of the simulation to be optimized

i) For the baseline geometrical parameters, changing the inlet helium pressure and velocity.

ii) Changing the longitudinal geometry: as mentioned above, look at the influence of the thickness of the slabs (looking e.g. at two cases, w=5 mm and w=10 mm, while keeping the total thickness =64 mm) on parameters of the flow. Look also at the effect of varying the width of the He channel with respect to the thermal balance and on laminarity of the flow.

iii) Changing the surrounding material instead of the stainless steel (to be discussed).
iv) Aerodynamic design of the vanes (to be discussed).

5. Operational scheme

i) Take off time of the amplifiers <10 min (with the cryogenic circuit running beforehand).

ii) Maximum expected operation 10 hours per day, with typical running scheme 5 days per week.

iii) Two 100-J and two 500-J laser beamlines must be capable to run simultaneously, with two amplifier heads of respective size per each beamline. The designed cryogenic system should provide redundancy for later addition of two other beamlines.

5. Baseline geometry

The below scheme provides a baseline dimensional layout of the two 100-J and two 500-J beamlines.

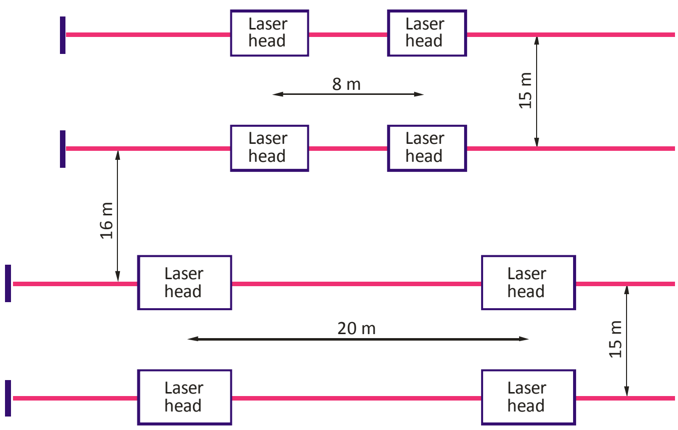

Figure 5: Schematic layout of the cryogenic laser amplifier: two 100 J and two 500 J beamlines.