# UPGRADE STRATEGIES FOR THE PROTON SYNCHROTRON BOOSTER DUMP AT CERN

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## *Abstract*

CERN's LHC Injection chain Upgrade (LIU) involves a revision of the Proton Synchrotron Booster dump, which was designed in the 1960's to cope with beam energies reaching 800 MeV and intensities of 1e+13 particles per pulse. Thermo-mechanical studies highlighted the need for an upgrade of the dump, so that it is capable of withstanding energies in the order of 2 GeV and intensities up to 1e+14 particles per pulse. This paper proposes a new design of the dump in the light of various constraints and choices such as the geometry, materials and the integration of the required cooling system. Further topics discussed include the strategy for dismantling the old device, which has been continuously irradiated for almost 40 years and presents a difficult access. Therefore, a detailed ALARA procedure is being prepared in order to carry out the upgrade works in the area.

## INTRODUCTION

The Proton Synchrotron Booster (PSB) will be upgraded, to make it able to withstand and accelerate the beam provided by the upcoming Linac4 at CERN. Table 1 summarises the current and upgraded beam parameters.

The PSB beam dump has to cope nowadays with much higher energies and intensities than the ones it was initially designed for (800 MeV, 1e+13 p+/pulse). Moreover, the active cooling system suffered a failure several years ago, and the age of the dump strongly suggests a renewal.

In this paper, some results of the numerical analyses of the still-in-use PSB beam dump are presented, confirming the need for a replacement. The conceptual design of the new dump and the procedure for the removal of the old dump and shielding are also described.

Table 1: PSB beam parameters

| **Parameter** | **Unit** | **Current Beam** | **Upgraded Beam** |
|---|---|---|---|
| Extraction energy $E_0$ | GeV | 1.4 | 2 |
| Pulse length $\tau$ | μs | 1.66 | 1.66 |
| Pulse period $T$ | s | 1.2 | 1.2 |
| Average current $\bar{I}$<br>$\bar{I} = I^* \cdot \tau / T$ | mA | 4.27E$^{-3}$ | 1.335E$^{-2}$ |
| Peak current $I^*$ | mA | 3088.2 | 9650.6 |
| Average Beam Power $\bar{W} = E_0 \cdot \bar{I}$ | kW | 6 | 26.7 |
| $1\sigma$ Max. Beam Size | H x V cm | 1.64 x 5.61 | 1.46 x 5.16 |
| $1\sigma$ Min. Beam Size | H x V cm | 0.42 x 0.81 | 0.37 x 0.71 |

## STATUS AND MOTIVATION FOR CHANGES

The present beam dump is a cylindrical object, 22 cm in diameter and 48.3 cm long. It consists of a collection of 13 Fe37 steel-disks, assembled in decreasing order of thicknesses, from 100 mm to 2 mm, with a constant 4 mm gap in between them.

A single, contiguous Stainless Steel cooling pipe runs through these disks, forward and backward six times at different, radially spread out locations, as seen on Fig.1.

The dump is located at the end of the BTM beam line, after the PSB extraction line, and connected upstream to the beam pipe. More than four meters of beam pipe and the dump core are placed in a 5 meter-cavity inside a wall and shielded with concrete blocks (Fig.2). This shielded cavity is open to the atmosphere, so that air can freely flow inside it, around the dump and in between its disks, hence allowing natural convection. Nowadays, this is the

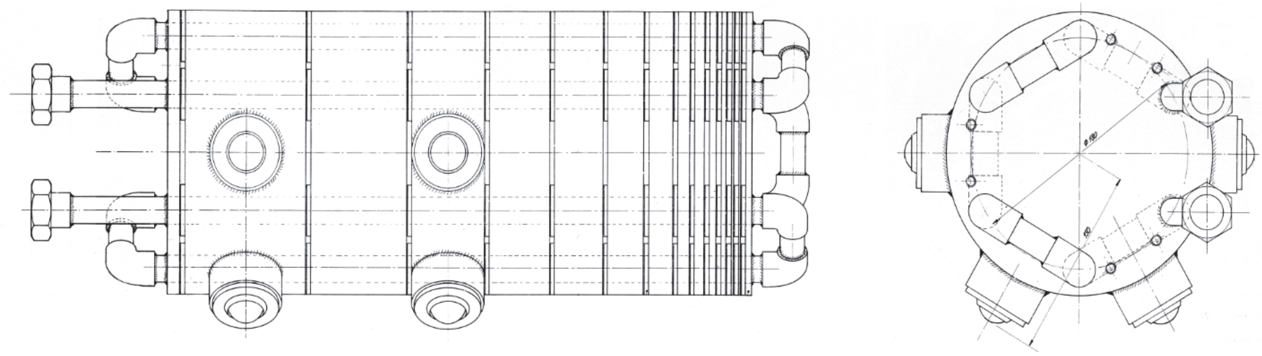

Figure 1: Drawing of the current beam dump core.

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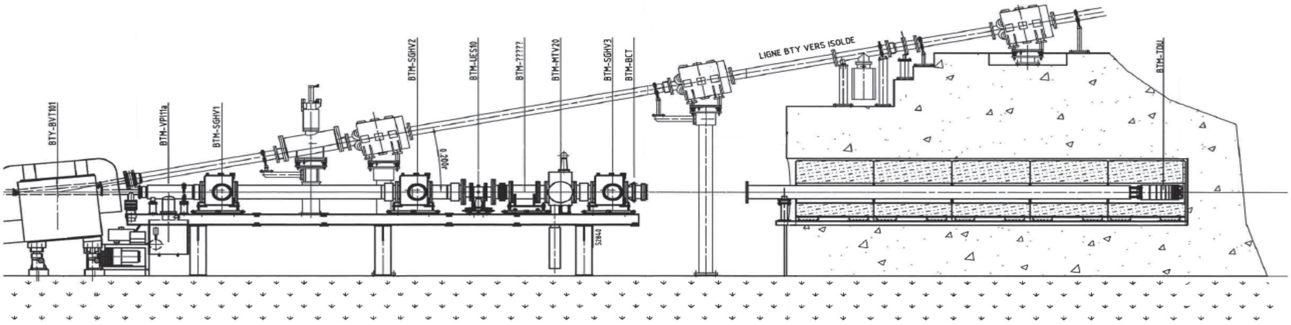

Figure 2: BTM and BTY beam lines on the left and shielded cavity with beam pipe and dump core on the right.

only means of evacuating the heat radiated from the object, since, after over 20 years of operation, the cooling pipes were disconnected from the water station when leaks were detected.

Also, in the past, the beam pipe contained within the cavity experienced some vacuum leaks, and it was consequently detached from the beam line and disconnected from the vacuum system. The beam travels today in air for over 6 meters before it reaches the dump. Hence beam sizes are larger, causing possible spread of particles out of the dump.

Thermal analyses show that without any type of forced cooling, but only with natural convection, dangerously high steady sate temperatures over 1300°C are reached at the core already today [11]. Figure 3 shows the distribution of temperature in a section of the beam dump, after reaching steady state and considering current operational beam parameters in the worst case scenario.

In addition, increasing the intensity with the upgraded beam from Linac4 would almost proportionally increase the working temperature, while the increase of energy to 2GeV would require a much longer dump.

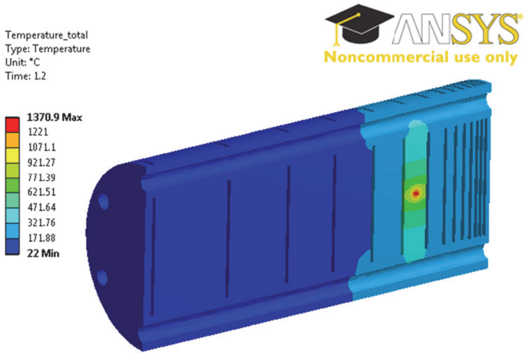

Figure 3: Steady state temperatures in the current dump for beam parameters in the worst case scenario.

## NEW CONCEPTUAL DESIGN

Due to space and intervention limitations in the PSB extraction area, the sole possible location for the new dump is the same where the old dump is at present. Several driving principles are therefore considered for the development of the design of the new dump, which are a direct consequence of this choice.

The design has to be as simple as possible to maximize reliability, reduce assembly difficulties, and to ease manufacturing complexity. Indeed, due to the fact that the dump core itself could not be directly accessed without a major interruption in the beam availability, no in-situ maintenance can be done. In this context, redundancies must be foreseen since the earliest stage of the design.

Finally, any possible issue linked to future dismantling should also be accounted for.

### *Design Considerations: Geometry*

The proton range and the development of secondary particles at 2 GeV require the dump to be at least 130 cm long when entirely made of Copper [6].

The diameter of the new dump core is defined to intercept up to 5$\sigma$ of the upgraded maximum beam. Thus, beam size variability has been estimated [3]. In this context, it is essential to consider not only maximum beam sizes – to dimension the dump as stated – but also minimum sizes, which directly and strongly affect the maximum peak temperatures in the dump core and consequently the mechanical stress. Both extremes are therefore constraining factors, carefully considered in the design.

To lower the stress level, and also to allow natural air cooling and thermal radiation to play a role in the heat extraction from the dump, a multiple-disk like geometry has been chosen for the new design – similarly to its predecessor. However, unlike in the old design, disks increase in thickness through the depth of the dump, to keep a quasi-uniform distribution of power throughout them, which enables more efficient cooling.

### *Cooling System*

Water cooling is mandatory to extract the almost 27 kW of average power of the future beam. The minimum cooling flow is estimated at ~2m$^3$/h, when water at ambient temperature is used. The cooling pipes have to lie close to the position where the maximum peak of temperature is located – i.e. the beam axis – to increase cooling efficiency, provided that radioactive activation of water is kept within acceptable limits. Also, to improve cooling reliability, a redundant water circuit is implemented.

A solution with forced air cooling was proposed but then discarded, due to the impossibility of having a closed air loop with enough flow in this particular area of the tunnel.

### *Choice of Material*

Based on the principles of simplicity and low-maintenance, the dump core was chosen not to work under vacuum. At the same time, mechanical connections are preferred over welding, while the choice of material was directed to basic metal compounds, for which thermal and mechanical properties are well known and their workability and behaviour in extreme conditions (such as ionizing radiation) is well assessed.

Concerning the choice of material, both thermal conductivity and mechanical strength need to be maximised. On the other hand, the induced activation at the required energy has to be minimised. At this regard, low density, low Z metals are preferred for the inner part of the core, where the beam hits directly. As for the outer part, good thermal conducting and higher density metals should be used, in order to optimise heat extraction and possibly have a first shielding of the developing particle cascade. Aluminium alloys were distinguished as good candidate materials for the inner core. Stainless Steel and Copper alloys were identified as suitable for the outer core, mainly due to their good thermal properties and high ductility, which help to keep the stress levels low.

## DISMANTLING STRATEGY

The procedure to dismantle the old beam dump is being defined following the ALARA approach [10], i.e. in such a way that the dose absorbed by the working personnel is kept 'As Low As Reasonably Achievable' at all times. This implies the creation of a dose rate map of the area where the works will be performed, a detailed list of the actions taken, with the time required for each one of them, a planning of the number of workers executing the operations and the total estimated dose absorbed by each person.

Furthermore, the personnel involved has to be trained for the tasks they will perform, a video of the whole operation will be recorded and the dose absorbed by the personnel will continuously be monitored, in order to minimise radiation exposure and avoid unnecessary risks.

Due to constraints in space in the area and in order to facilitate site access and the disposal task, it is necessary to temporarily dismantle part of the BTM and BTY beam lines in front of the dump cavity, as well as some other equipment. Accordingly, proper transport arrangements are foreseen to access the area and special tools are being designed and manufactured to pull out the old device and to take care of its disposal. Due to their activation, it is planned to dismantle and dispose of the dump core, the segment of beam pipe attached to it, as well as the concrete shielding around.

In order to proceed with the works, different scenarios have been considered, each accounting for a different possibility of a failure while performing a particular task. It is important to keep abreast of possible risks and maintain readiness for action, should any problems be encountered.

In summary, the main issue regarding the dismantling works constitutes the high potential dose rates, caused by 40 years of continuous irradiation of the dump core. To properly prepare the ALARA procedure, simulations of the region are being performed, in order to estimate dose rates in several locations and at different times. These simulations will be then validated by in-situ measurements done by the Radioprotection Group before any dismantling work could start.

## CONCLUSIONS

In this paper, the constraints and requirements regarding the design of the new beam dump for the upgraded Proton Synchrotron Booster at CERN have been presented. Beam parameters - such as beam energy, intensity and size - as well as the geometry of the device, the integration of a cooling system and the choice of materials have been carefully taken into account.

The procedure for the dismantling and disposal of the old beam dump has also been approached.

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