7.6.3 Pairs and radiative Bhabhas power deposition

Although the ±10 m region around the IP is free from spent beam loss, lower energy radiative Bhabhas and $e^+e^-$ pairs — which experience large disruption during the bunch collision — are over-focused by the IR doublet quadrupoles. The power densities deposited on the beam pipe (shown in figure 7.6.5) are smaller than the 3 W/m limit set by cooling capacity of the cryogenic system for the s.c. IR quadrupoles [33].

7.7 Main Beam Dump System

This section discusses the main characteristics, features and safety aspects of the main beam dump system. Many of the basic considerations of the dump system are discussed in detail in [83]: in the following, therefore, emphasis is placed on those aspects that differ or are new. A more detailed description of certain subcomponents of the system can be obtained from the cited references. The numbers quoted are for the design beam power for the 500 GeV machine (11.3 MW). Where necessary, comments concerning the 800 GeV upgrade (17.5 MW beam power) are included.
### 7.7 Main Beam Dump System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>250 GeV</th>
<th>400 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_0$, particle energy</td>
<td>250 GeV</td>
<td>400 GeV</td>
</tr>
<tr>
<td>$N_t$, particles per bunch train</td>
<td>$5.64 \times 10^{13}$</td>
<td>$6.84 \times 10^{13}$</td>
</tr>
<tr>
<td>$\nu_{rep}$, repetition rate</td>
<td>5 Hz</td>
<td>4 Hz</td>
</tr>
<tr>
<td>$I_{ave}$, average beam current</td>
<td>45 $\mu$A</td>
<td>43.8 $\mu$A</td>
</tr>
<tr>
<td>$W_t$, energy per bunch train</td>
<td>2.3 MJ</td>
<td>4.4 MJ</td>
</tr>
<tr>
<td>$P_{ave}$, average beam power</td>
<td>11.3 MW</td>
<td>17.5 MW</td>
</tr>
</tbody>
</table>

Table 7.7.1: Beam parameters relevant to the beam dump system for the 250 GeV main linac beam and its 400 GeV upgrade option.

#### 7.7.1 Requirements and basic concept

The important beam parameters relevant to the dump are given in table 7.7.1. The current high-luminosity parameter set represents a 50% increase in the average power requirement compared to the CDR parameters [83]. Solid dumps are ultimately limited by the thermal conductivity of the material, and already become technically difficult beyond several hundred kW of beam power: in the MW regime, therefore, the only reasonable and technically feasible solution is a water dump, which can handle the high power by a sufficient mass flow of water towards an external heat exchanger [87].

Figure 7.7.1 shows the conceptual layout of the main parts of the dump system. The same dump is used for the main spent beam, and for the fast emergency extraction line (FEXL), described in section 7.6.2 (the main extraction line is described in section 7.6); as a result the dump requires an entrance window at both ends of the water vessel. A single cooling system (per side) is intended to serve both the main spent beam dump and the beamstrahlung collimator (section 7.6.2); if a second IR is constructed, then the same cooling plant can also be used for the additional dumps, since the total power at any given time can never exceed the maximum single beam power.

#### 7.7.2 Design of water vessel

Most of the beam power should go into the water and not into the mechanical container: hence the vessel must be built from a minimum amount of mechanically strong and corrosion resistant material, which in addition represents a small source of induced radioactivity. The dump consists of about 11 m$^3$ of water, which is housed in a 10 m long (27.7 radiation length) cylindrical titanium vessel, with a radius of 60 cm (6.3 molière radii), and a wall thickness of 15 mm.

According to 250 GeV shower simulations using the MARS code, energy escaping from the absorber is at the 1–2% level, and is dominated by radial leakage. Since penetration of the shower varies only logarithmically with energy, we can assume that the leakage power out of the vessel and into the surrounding shielding scales approximately linearly with incident beam power: an increase of ~50% is therefore expected for the 800 GeV upgrade.
Although relatively small, the leakage power is still more than 100 kW, and an inner shell of aluminum is required to significantly reduce the power density on the outer concrete shielding [86]. Aluminium was chosen because of its low residual radioactivity and high thermal conductivity. The removable shield will be thermally coupled to the water vessel. Gaps between the vessel and shielding, or within the shielding volume must be kept to a minimum to reduce air activation. For further details on radiation safety issues see section 8.3.

The absorption of all \( N_t \) particles of one bunch train leads to a certain energy distribution in the water, which directly translates into an instantaneous temperature rise with its maximum \( (\Delta T_{\text{inst}})_{\text{max}} \) somewhere on the shower axis. If \( E_0 \), \( N_t \) and the absorber material are fixed, \( (\Delta T_{\text{inst}})_{\text{max}} \) only depends on the area of the incoming beam. The risk of boiling is avoided by:

- pressurising the water to \( 10^6 \) Pa (10 bar), which pushes the boiling point to about 160°C; and
- limiting the instantaneous temperature rise to < 40°C (assuming that the water has a temperature of ~50°C before the arrival of the beam).

The latter constraint sets a minimum RMS beam radius at the dump of 19 mm and 30 mm for \( E_{\text{beam}} = 250 \) GeV and 400 GeV respectively. For an undisrupted beam (i.e. no collision), the RMS beam size at the dump is only \( 1 \times 0.4 \) mm\(^2\) which is far too small: therefore the effective spot size has to be increased by using a fast sweeping system [88], that distributes all the bunches of the bunch train around a circle of radius 5 cm at 250 GeV (8 cm at 400 GeV) on the face of the dump. The fast sweeping system consists of a set of orthogonal deflectors excited with a sinusoidal current of the same frequency but with a 90° phase shift. The frequency needs to be at least 1 kHz in order to evenly
7.7 Main Beam Dump System

distribute all the bunches from a single bunch train (950 \( \mu \text{sec} \)). Pulsed iron yoke dipoles sitting outside of the vacuum chamber will be used. Several independent modules in each plane are foreseen to allow safe operation should one fail. As an additional safety measure, the sweeper system will be triggered early enough to prevent the extraction of the bunch train from the damping ring should a failure in the system be detected.

### 7.7.3 Entrance and exit windows

Figure 7.7.2 shows the concept of the dump window. The beam passes through an exit window at the end of the vacuum system before it enters the water absorber through a second (separate) window: using two windows provides a level of redundancy in the event of a leak. The volume between the two windows requires a rough vacuum to avoid air activation. Windows for pulsed beams suffer from cyclic mechanical stress due to instantaneous heating. A 5 Hz operation and a 10 year lifetime gives in total about \( 10^9 \) cycles. Normally materials with high specific heat like beryllium are preferred; but given the required high number of cycles titanium alloys are good candidates. Available data for such alloys shows that the maximum allowed particle density \( (dN/dA)_{\text{max}} \) at the window as a function of the number of cycles (before failure) tends to a constant value of \( \sim 4 \times 10^{12} / \text{mm}^2 \) after \( \sim 10^4 \) cycles [89]. Unfortunately data only exists up to \( 10^7 \)–\( 10^8 \) cycles. However, even for the undisrupted beam, the particle density on the window is a factor of ten less than this limit due to the constraint from the instantaneous temperature rise of the water.

The titanium membranes in both windows are reinforced by graphite disks as shown
in figure 7.7.2. In the case of the (vacuum) exit window, the graphite (which is located on either side of the membrane) will help to conduct away the average power\(^1\) of 30 W/mm\(^2\) towards the heat sink at the circumference of the window. For the (water) entrance window, average heating is not a problem since the membrane is cooled directly from the dump water.

The performance of the window is only dependent on the peak particle density and average beam current, and not on the beam energy: therefore, the window can also be used for the 800 GeV upgrade, since the average beam current remains roughly the same, and due to the increased sweep radius, the peak particle density is also approximately constant. Since the performance is not energy dependent, experience can be obtained from tests at the TESLA Test Facility Phase 2 (TTF2), where such a graphite-titanium sandwich-like window will be installed as an exit window.

### 7.7.4 Water system

Removal of the heat dissipated by the beam in the water vessel will be done by a special water in- and outlet system. The flow of water though the vessel is dictated by two constraints:

- to renew the volume of water that the shower sees for each beam pulse, a flow of \(\sim 0.5\, \text{m/s}\) perpendicular to the shower axis (at the critical longitudinal position) must be guaranteed; and

- a continuous (bulk) flow of 100 kg/s, or 360 m\(^3\)/h of water towards an external heat exchanger is required to handle the average power.

The temperature drop between in- and outlet is \(\sim 30^\circ\) C. The heat exchanger is part of an ambitious water preparation plant, schematically shown in figure 7.7.3; the system must also handle the radiological and chemical aspects of the dump water.

It is expected that the dump water will remain in the closed system for the entire lifetime of the collider. For pure water, The following radioactive nuclei will be produced (half-life in brackets): \(^{15}\text{O}\) (2 minutes); \(^{13}\text{N}\) (10 minutes); \(^{11}\text{C}\) (20 minutes); \(^{7}\text{Be}\) (54 days); and \(^{3}\text{H}\) (12 years). The activity of the \(^{7}\text{Be}\) and \(^{3}\text{H}\) saturate at 66 TBq and 7.3 TBq respectively. After decay of the short-lived isotopes, the outside dose rate is mainly determined by the 478 keV \(\gamma\) particles from the \(^{7}\text{Be}\) decay, since the 20 keV electrons from tritium decay will not penetrate the walls of the water system. If distributed evenly in a total water volume of 10 m\(^3\), the estimated dose rate at the surface of a 300 mm diameter tube is about 500 mSv/h; this value will be reduced by two to three orders of magnitude if a few percent of the total water flow is passed through a resin filter which removes the \(^{7}\text{Be}\). In addition, the filter removes other particles and therefore maintains the purity of the water, which is essential for avoiding corrosion. Radiolitical damage of the filter material is reduced by a delay line in front of the filter to allow the short-lived products to decay.

\(^1\)Assuming an average current of 45 \(\mu\text{A}\)
There will be a small gas volume (most probably He) at the top of the dump vessel; it will protect the vessel from pressure waves induced by instantaneous heating in the event of a failure of the fast sweeping system. The gas buffer will also maintain the static pressure and compensate for slow expansion due to different average temperatures of the dump water. All gaseous constituents not dissolved in the water will accumulate in the buffer: special attention must be paid to hydrogen, which is produced via radiolysis with a rate of 3.61/s [85]. A catalytic hydrogen recombiner and a gas analyzing station will be connected to the buffer volume.

The system needs to be leak-tight at the level typically found in vacuum systems; this requires gas-tight components (pumps, heat exchangers, etc.), welded or metal sealed connections, and a proper choice of materials to avoid harmful water-chemical reactions. A water analysis station will monitor relevant parameters such as acidity, ion concentrations and conductivity. However the possibility of a leak requiring a repair or exchange of a component has to be foreseen. Once a leak has been detected by monitoring water pressure and level, the system will first be flushed into the storage container to remove the dominant source of radiation, allowing work to proceed on the necessary mechanical parts after a relatively short cool-down period.

All walls of the hall for the system have to be sealed with a special paint to collect leaking water. The primary cooling circuit is separated from the the general cooling
water by an intermediate secondary loop, which has a higher pressure than the primary one. The loop protects the general cooling water from being contaminated, in the event of leaks in either of the heat exchangers. The whole water system will be housed in the dump hall.

The design and fabrication of such a complex water dump represents a significant technical challenge. However, similar systems already exist: e.g. the 25 GeV, 2.2 MW water dump at SLAC [84]; spallation neutron sources like the SINQ at Paul Scherrer Institute (PSI); or research reactors. By using the experience gained at these and other facilities, a safe and technically feasible design can be achieved.

Bibliography


[27] N. Walker, Linear Tuning and Estimates for the Initial Beam Based Alignment Requirements for the TESLA Beam Delivery System (BDS), DESY TESLA-00-29, 2000.


