Area System 6: Beam dump

(Ver.4,2021-Mar-23)

Overview:

Beam dumps are distributed along the ILC accelerator and operate continuously during commissioning, regular operation, or they receive an abort beam in the event of a malfunction to prevent damage.

Tune-up dumps are used for commissioning and system tuning, where the beam energy is given by the maximum operating parameters of each accelerator section, but other parameters, such as the bunch charge, number of bunches per pulse, and pulse repetition frequency may be reduced compared to the nominal operating parameters. The maximum beam power for tune-up dumps is optimized for 60 kW and 400 kW, distributed before and after the ML, respectively. These beam dumps are designed with experiences of solid material dumps such as the aluminum dump of SLAC (120 kW) and the graphite dump of XFEL (300 kW); thus, no prioritized preparation is expected in the Pre-Lab period.

The main beam dump absorbs the electron or positron beam after collision at the end of each beamline. Because the beam power of full power operation after the 1-TeV upgrade will be rated at 14 MW, a pressurized water dump that is capable of 17 MW, including a 20% safety margin, was designed based on the 2.2-MW water dump at SLAC. In addition, a water dump rated at 8 MW will be prepared for 5 + 5 Hz positron production in the undulator scheme. During the Pre-Lab period, the engineering design of the water dump system, prototype test of the beam window, and its remote exchange will be carried out to improve the reliability of the system.

The photon dump is a special dump for undulator photons, which are used for positron production and pass through the target. The maximum power, including a 20% safety margin, is rated at 300 kW. Owing to the high concentration of photons by the undulator, the photon absorber should be well designed taking into account the effect caused by heavy local energy deposition. Two types of photon dumps have been proposed: water based and graphite based, they are located at 2 km downstream of the target.

It is very important to present a safe and concrete design for the main beam dump and photon dump, and it should be well described in the Engineering Design Report (EDR) at the Pe-lab stage. Finally, it needs to be noted that the main beam dump requires a large space for installation and will impact the civil design.

Dump	Max. Power	No. of units	examples
Tune-up	60 kW	9	Aluminum; SLAC, graphite; XFEL
Tune-up ML	400 kW	2	Graphite; XFEL (300 kW)
Undulator photon	300 kW	1	Conceptual designs (water, graphite)
Main beam dump	17 MW (1 TeV)	2	SLAC (2.2 MW), JLAB (1 MW)
Undulator 5 + 5 Hz	8 MW	1	Same as main dump

Area System Beam Dump: WPs:

WP- 17: System design of the main beam dump	Engineering design of water flow system
	Engineering design and prototyping of components; vortex flow in the dump vessel, heat exchanger, hydrogen recombiner
	Engineering design and prototyping of window sealing and remote exchange
	Design of the countermeasure for failures / safety system
WP- 18: System design of the photon dump for undulator positron source	System design and component test of open-window water dump
	System design and component test of graphite dump

WP-17: System design of the main beam dump

(Ver.4,2021-Mar-23)

Technical Preparations Plan:

The SCJ and MEXT's ILC Advisory Panel stated technical concerns regarding the reliability, earthquake protection, and stability of the window of the main beam dump, reaction between the high-energy beam and water, and containment of activated water. In order to respond to these concerns, it is very important to present a safe and concrete design of the main beam dump during the Pre-lab period. This plan is proposed to proceed with the design of the main beam dump and to demonstrate the stability of the window and its handling procedure.

The design work will be carried out with the collaboration of experts from the field of high-power targets and dumps worldwide. CERN operates beam dumps for large accelerators and high-power beam dumps, and SLAC and JLAB have experience with water-circulated beam dumps. KEK will lead the system design of the beam dump facilities, ensuring environmental and radiation safety in collaboration with the government, industry, and the scientific community. The engineering design of the vortex flow system in the water dump vessel and the overall water circulation system will be done following the experiences at SLAC and JLAB. The stability of the window will be confirmed from the perspective of radiation damage and mechanical robustness. The Ti alloy, Ti6Al4V, was selected as a window material following the experiences involving high-power targets and dumps globally, which was mostly conducted by proton beams. Further studies that increase the robustness will continue through collaboration. The mechanical robustness of the window will be confirmed through sealing prototypes and demonstration of the remote exchange for maintenance work under high radiation condition. A scheme for monitoring the integrity of the window will also be studied. The design for safety, that is, earthquake protection, containment of activated water, including the countermeasure for failures, is a major engineering issue to be addressed. The maintenance plan will be presented with a concrete design of equipment of the dump system. These will be conducted through collaboration with industries.

Goals of technical preparation:

Establish the engineering design of the whole dump system.

List of items::

Items
Engineering design of water flow system
Engineering design and prototyping of components; vortex flow in the dump vessel, heat exchanger, hydrogen recombiner
Engineering design and prototyping of window sealing and remote exchange
Design of the countermeasure for failures / safety system

Status and Prospects:

The design of the ILC main beam dump was developed in the mid-2000s by experts in Europe and the US. In 2012, the basic design was established as an 18-MW water dump and compiled into the TDR.

In 2017, a group was set up at KEK to advance the design of the ILC beam dump, and this group exchanges information and consults with beam dump experts at CERN, SLAC, and JLAB. In addition, the design of the dump system for radiation safety management at the candidate site and the design of a large underground cavern for the main dump and its utilities are currently being carried out in collaboration with industry and academia.

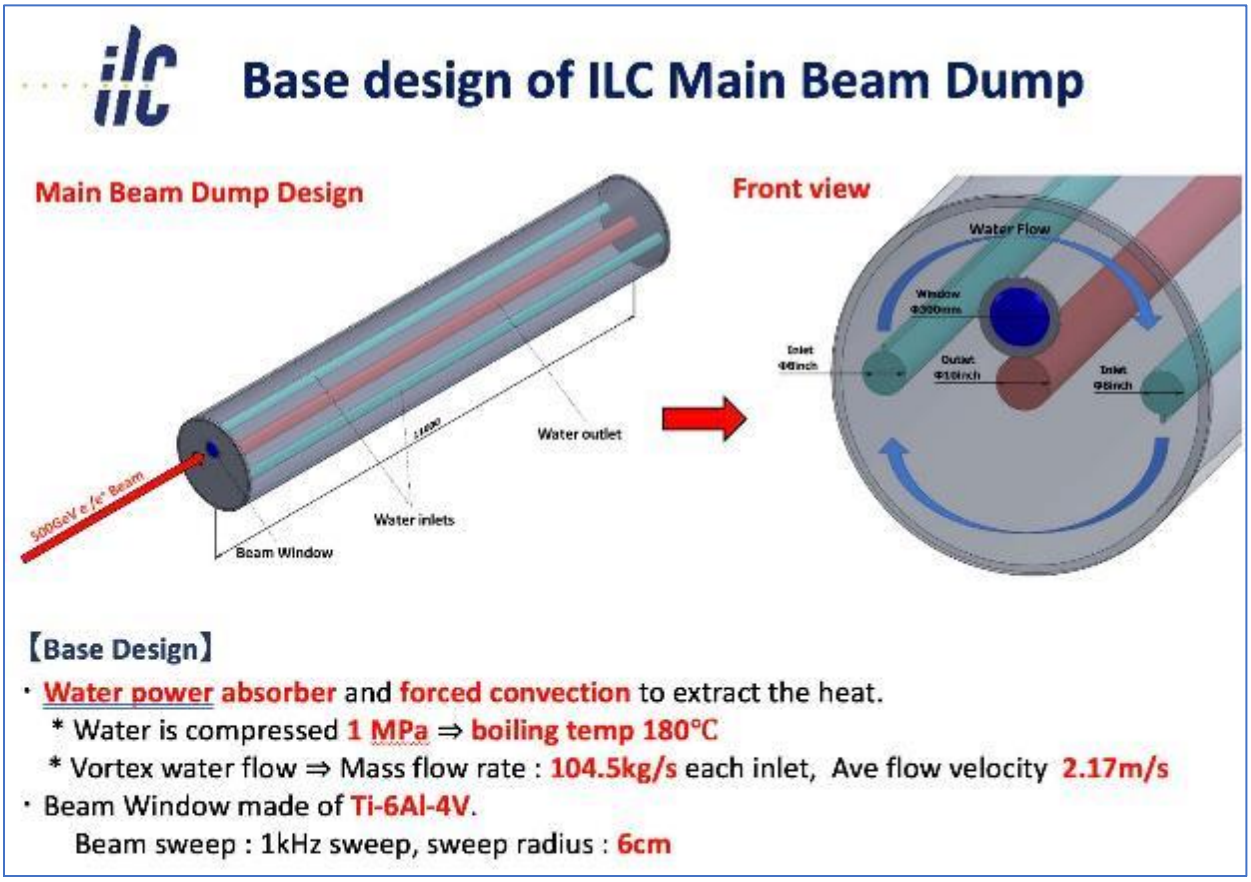
The main beam dump has been designed based on the 2.2-MW water dump designed at SLAC, which was operated at 0.75 MW. JLAB has another water dump, which is a 1-MW design that is currently used for CEBAF operations.

At this point, the design for ILC is a conceptual one that meets the basic parameters, and must proceed with its embodied design. The water that serves as an absorber for the beam is supposed to rotate in the tank as a vortex flow to sweep out the heated portion. Although there is a conceptual design of the inlet and outlet, to date, there is no operational design.

Tritium accumulates in the water owing to activation by the beam. Although the radiation of tritium is weak, a solid water leakage countermeasure is desired. There remains the need for a detailed design of the beam window and water circulation system considering these factors.

The radiation dose in the dump room will increase owing to severe activation of the dump vessel and its surrounding shielding over the years of operation. Therefore, the periodic replacement of the beam window will be performed remotely. This mechanism, including the structure for mounting the window, has not yet been designed.

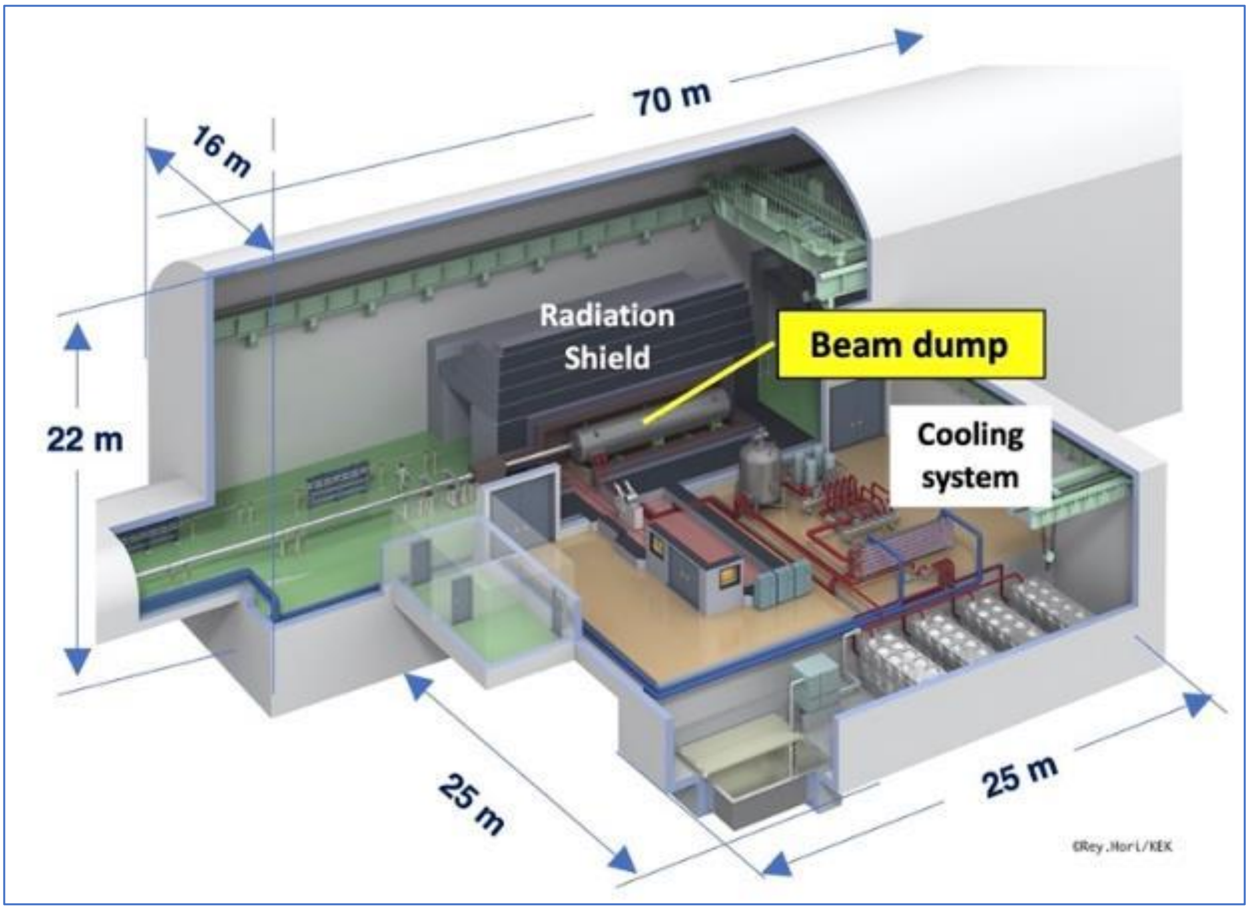
The maximum power based on the latest beam parameters is 14 MW for a 500-GeV beam and 2.6 MW for a 125-GeV beam. The beam dump is designed to be up to 17 MW, assuming a 20% margin. A scenario to upgrade the dump step by step with experience as the ILC beam energy increases can be considered. However, only water dumps are considered to be capable of absorbing beams above MW, and there is no significant difference in the mechanical structure for absorbing beam power within the envisioned range. The most significant difference is the water pressure to suppress boiling, which is 1 MPa for 1 TeV and 0.3 MPa for 250 GeV, but it is not technically difficult. In addition, an important issue is the activation of the dump vessel and its surroundings, which greatly limits the maintenance work. Based on these considerations, it is assumed that the main beam dump designed for 1 TeV will be used from 250 GeV, and can be operated with a margin of safety. Furthermore, to cope with long-term heavy failures, we are planning to secure in advance a space where a second dump can be additionally installed just before the first dump, and this has been incorporated into the current civil design.



Base design of ILC Main Beam Dump

【Base Design】

- **Water power absorber** and **forced convection** to extract the heat.
  - * Water is compressed **1 MPa** ⇒ **boiling temp 180℃**
  - * Vortex water flow ⇒ Mass flow rate : **104.5kg/s** each inlet, Ave flow velocity **2.17m/s**
- Beam Window made of **Ti-6Al-4V**.
  Beam sweep : 1kHz sweep, sweep radius : **6cm**



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WP-18: System design of the photon dump for undulator positron source

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Technical Preparation Plan:

The photon dump for the undulator positron source, which should absorb an average power of 120 kW for the 250-GeV high-luminosity case, needs to be changed from TDR, where a water dump similar to the main beam dump was assumed. For the possible future option of a 10-Hz collision, it is rated at 300 kW, including a 20% safety margin. Owing to the high concentration of photons by the undulator, the local energy deposition in water is high and the water should be pressurized to about 12 atm to prevent temporary boiling during or at the end of each pulse. The window should be Ti alloy more than 1-mm thick to resist water pressure, and such a thick window will suffer from fatigue through the high thermal cycles during each pulse and severe radiation damage. Two alternative designs are currently proposed to address this issue. One is a water-based dump and the other is a graphite-based dump, both of which will be installed 2 km downstream of the positron target to reduce the density of the photon load. The 2 km photon transport line passes next to the BDS and shares the BDS tunnel. Furthermore, the dump can be installed with shielding in the space created at the junction of the RTL (Ring to Main linac) and the BDS beamlines. These designs are based on heat and radiation damage analysis, and need to move forward by incorporating technical issues, especially power absorption structures and the maintenance of activated equipment.

In order to respond to the safety concerns expressed by the SCJ and the MEXT panel, it is very important to present a safe and concrete design for the photon dump as well as a maintenance plan and accident countermeasures during the Pre-lab period. These design works will be carried out in collaboration with experts from the field of high-power beam targets and beam dumps throughout the world, as well as those with experience in high-power photon absorbers for XFEL and fourth-generation light sources. Prototyping of the key structure is expected.

Goals of technical preparation:

The system design of the photon dump is established at an engineering level, including the photon absorption structure, infrastructures for cooling, and the maintenance of the activated equipment.

List of items::

Items
System design and component test of open-window water dump: water flow and cooling of upstream windows
System design and component test of graphite dump; cooling of graphite absorber on copper

Status and Prospects:

The photon dump for the undulator positron source (Figure 1) should absorb an average power of 120 kW for the 250-GeV high-luminosity case and 108 kW for the 500-GeV high-luminosity case. For the possible future option of a 10-Hz collision, it is rated at 300 kW, including a 20% safety margin. A water dump similar to the main beam dump was assumed in the TDR. In contrast to the main water dump for electron and positron beams, the photon beam cannot be swept magnetically. Owing to the high concentration of photons, a cross section of below 2 mm, the local energy deposition in water is high, and the water should be pressurized to about 12 atm to prevent temporary boiling during or at the end of each pulse. A 1-mm-thick Ti-window is required to resist water pressure, and such a thick window will suffer from fatigue through the high thermal cycles during each pulse and severe radiation damage. To solve these difficulties, two different types of dumps have been proposed, both to be placed at about 2 km downstream of the positron target.

The open-window water dump, shown in Figure 2, is inspired by the main dump, but running at a pressure of 1 atm. A vertical flow of water through the tank ensures the evacuation of the heated part of the water. To bypass the issue of a vacuum and watertight stationary beam window at the upstream side of the water tank, a free small aperture of 3-5 cm diameter is foreseen at this location. The parasitic loss of water through this aperture can be recollected, see Figure 3 and recirculated back into the main water circuit. A double-walled beam window is located approximately 10 m upstream of the dump to separate the water section and beamline. Each window will be made of Ti alloy, Ti6Al4V, about 10~14 cm in diameter, and will be 0.2~0.4-mm thick. The double windows will be cooled by He gas, which flows in a closed circuit between them with 100 m/s flow rate. The window unit will mechanically be tumbled in a circular way, e.g., with a 3-cm radius and velocity of 2.5 cm/s, to spread the average heat input and radiation damage over a larger surface. The buffer gas volume between the window and the water tank , see Figure 2, is flushed with a small gas flow to protect the Ti-window from corrosion by water vapor, if so required.

Another type of photon dump is proposed based on graphite, which tolerates high temperatures (Figure 4). Locating a graphite dump 2 km from the target and receiving photons at a shallow angle of 10 mrad will make the thermal distribution acceptable. The entire graphite part will be 1-cm thick, 50-cm wide, and 4-m long, and it will consist of several short units which needs to be attached or brazed on water-cooled copper. All graphite units with a copper base will be in vacuum, therefore no beam window is required.

In both designs, basic studies on heat, stress, and radiation damage have been studied using the simulation code of ANSYS and FLUKA. Further studies should be conducted to establish an engineering design that includes infrastructure, maintenance, and failure scenarios. In the case of photon dumps, unlike main dumps, the radiation dose during maintenance and replacement operations is not so severe. Therefore, it is expected that the photon dump will be upgraded step by step as experience is gained along with the operation of the ILC.

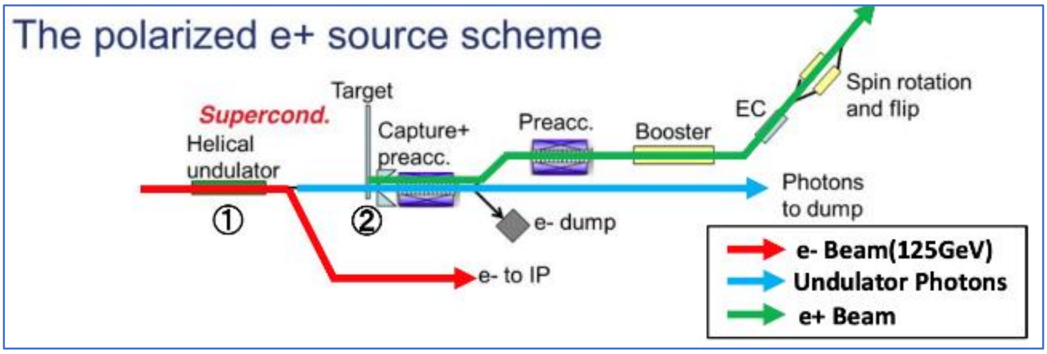

Figure 1: Configuration of undulator positron source

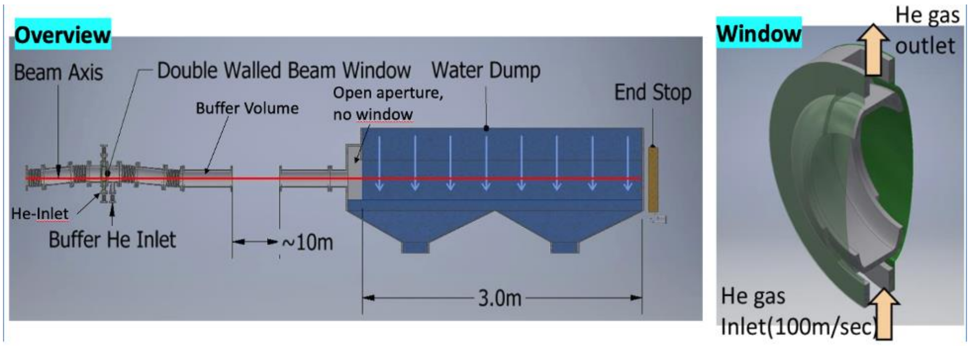

Figure 2: Layout of water-based photon dump system.

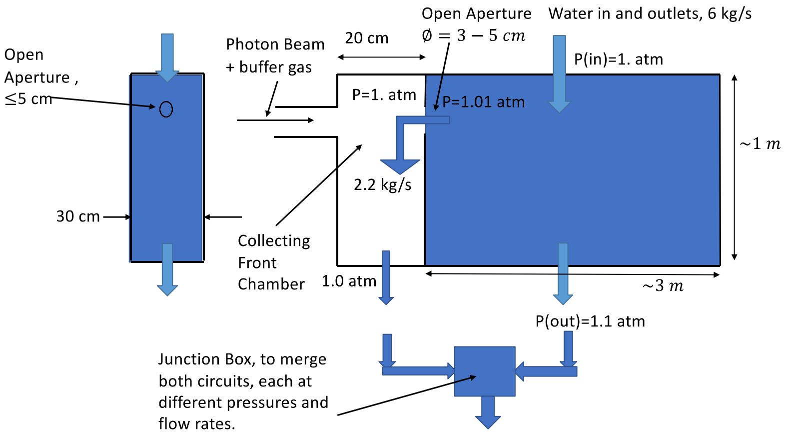

Figure 3: Concept of the water part with an open-window.

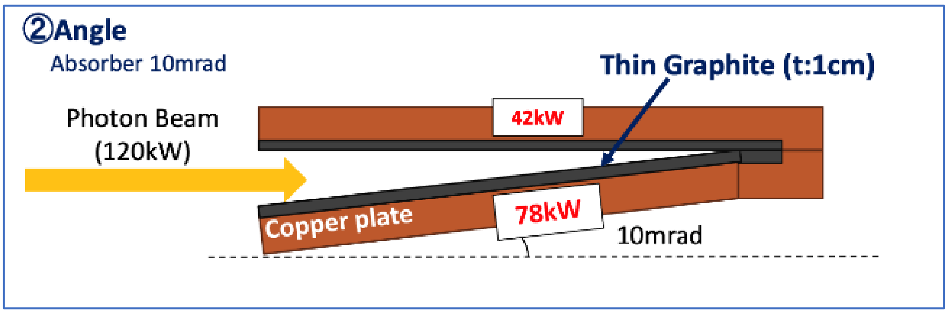

Figure 4: Concept of graphite-based photon dump.