BEAM DUMP SYSTEM (WBS 1.6)

i. System Introduction

An internal beam abort system capable of absorbing the full energy heavy ion beam of the RHIC accelerator once per hour has been designed. The system will be comprised of 3 major subsystems, 1) the kicker magnets, 2) the pulsers and pulse forming networks (PFNs) and 3) the dump absorber. The beam abort systems will be located in the outer straight sections downstream of the 10 o'clock IP between Q3 and Q4 (see Fig. 6-1). In this configuration, the lattice parameters favor extraction in the horizontal plane. The kickers, actually composed of five modules, will be located at Q3 downstream of the crossing point. They will deflect the beam horizontally towards the ring center, onto the C-C absorber whose front face will be 23.5 m downstream from the midpoint of the kicker modules, and just upstream of Q4.

The energy stored in the beam will be about 200 kJ at top energy for all species assuming 60 bunches with nominal intensity, i.e. 10^9 in the case of gold beams. This energy is large enough to cause component damage if lost in an uncontrolled manner, but small enough to be disposed of in an internal beam dump system provided that the expected secondary particle spray from the dump absorber can be contained sufficiently well so as not to overheat and, thus, quench the superconducting magnets downstream. The stored beam energy can be disposed of within the constraints of the lattice without damage to the equipment provided that the materials in the dump absorber have been carefully chosen and the beam is dispersed over a sufficiently large area on the face of the dump absorber.

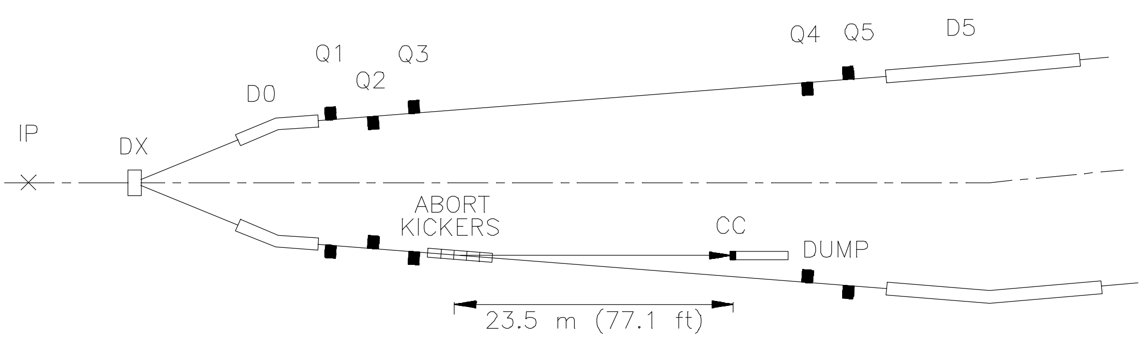

Fig. 6-1. Location of abort kickers and beam dump in the yellow ring at 10 o'clock.

The abort system will be used routinely to safely dump beam when the luminosity has declined to an unacceptable level or whenever deviations from normal operations are detected which may cause the beam to stray beyond a safe region within the vacuum chamber. The system response time will be sufficiently fast to begin safe extraction of the beam in all conceivable cases of accidents or beam instabilities within 4 turns (~52 µsec), and the beam will then be aborted within a single turn (~13 µsec).

The task will be to eject a small, potentially damaging beam which is traveling inside a larger "dump aperture," i.e. the phase space permitted by physical apertures in the collider. In the event of malfunction, when an incipient excursion toward a physical aperture is detected, the abort system will react quickly enough so that the beam has no chance to escape the dump aperture altogether. At the same time, however, control over the exact beam position or size will be already deteriorating. Therefore, not only the beam, but the entire dump aperture phase space must be transposed onto the dump absorber. This requirement determines the apertures of physical elements within the beam dump channel. The 18 m long beam tube between the five kicker modules and beam dump has the standard warm bore dimensions of 12.7 cm o.d. The layout of the dump components and their locations within the 10 o'clock tunnel structure are shown in Fig. 6-2.

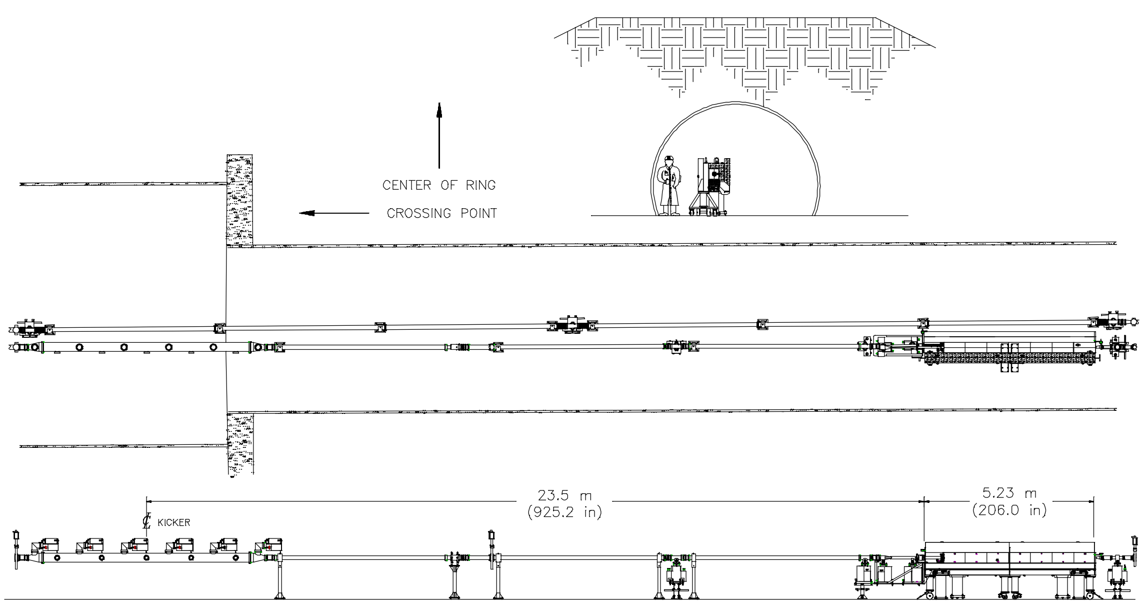

Fig. 6-2. Placement of beam dump components within Collider tunnel. Area shown is yellow ring at 10 o'clock.

In the RHIC rings, physical aperture requirements are determined at injection, with $\beta^*= 10$ m at all crossing points, to accommodate a 6σ beam halo for gold beams, whose transverse emittance has been enlarged to 15π mm·mrad (from the nominal normalized 10π) by intrabeam scattering. The corresponding (un-normalized) dump aperture is ~7π mm.mrad. In practice, after establishing running conditions at top energy (where physical apertures exceed 10σ, even after intrabeam scattering has enlarged the emittance to 40π mm·mrad), a collimator will be inserted into the beam halo in each ring. A rapid increase in losses on these limiting aperture collimators is expected to be the most likely trigger for the abort system should malfunction occur.

The kicker system must operate over the range of energies from RHIC injection to the maximum energy of RHIC ($B\rho$ = 97.5 to 839.5 T.m). The nominal deflection angle required of the kicker system will be 1.6 mrad at all energies. The total magnetic length of the five kicker magnets is 6.10 m, which then requires a nominal magnetic field strength of 0.22 T in each magnet for the highest RHIC energies to ensure adequate deflection angle. In order to avoid uncontrolled beam loss in case of a single pulser or magnet failure, the kicker module will be built of five individual magnets, each with its own pulser. In the event of a failure of a magnet or pulser, the 80% deflected beam (1.28 mrad) will still clear the limiting aperture of 17.75 mm in the dump and project onto an ellipse having a horizontal extent of ±11.3 mm on the face of the dump absorber. Because of the aspect ratio of the length to diameter dimensions of the structure, it is difficult to visualize the path of the circulating and ejected beams. Figure 6-3 shows this area schematically, with a normal longitudinal scale, but with transverse dimensions increased by a factor of 50. The horizontal beam envelopes of ±11.3 mm width are shown for both the nominal minimum and maximum kicker deflections as they impact the absorber face.

The circumference of RHIC is 3833.8 m, resulting in a minimum pulse length for the kicker system of 12.8 µs. In order to facilitate the abort system design, a gap of ~1 µsec (corresponding to 4 missing bunches) will be provided. Thus, the kicker pulser and the pulse forming network must be designed with a rise time to achieve the nominal deflection of 1.6 mrad within this gap. After the initial rise, the excitation current will continue to rise by ~45% and oscillate for ~13 µsec, which will provide the necessary horizontal dispersion of the bunches on the face of the absorber.

The ion beams in RHIC will always be bunched, and as mentioned above, a gap of 1 µsec will be left in the circulating beam so that, in principle, the kicker will be able to rise to nominal field without imparting a partial deflection to some of the beam during the risetime. Even a small amount of partially deflected beam has the potential to quench one of the high β quadrupoles. This "empty gap" concept is partially invalidated by Au ions which leave their rf buckets and "leak" into the gap. A variety of possibilities for countering this problem exist. If the limiting aperture collimators are positioned one sextant away from the dump kickers, tracking studies have shown that the vast majority of any beam in the gap would be "caught" by the collimators since the phase difference in 1/6 of a ring is very close to -90° and nearly independent of lattice tune. Another possibility is to apply voltage to the transverse damper, a fast strip line kicker, in each ring synchronized to the gap. This would perturb the transverse betatron amplitudes of any ions in the gap, thereby driving them onto the collimators. Finally, a scheme for confining Au ions in "macro buckets" has been developed which would prevent ions from entering the gap in the first place.

As mentioned above, the kicker must disperse the beam bunches on the face of the dump absorber to preserve the integrity of the dump material. The worst case will be the ejection of the Au beam immediately after acceleration. In contrast to the situation with proton beams, the energy density will be highest at the dump entrance due to the Z^2 dependence of dE/dx. Dynamic stress analysis showed that the dispersal achievable by the kickers was not sufficient to insure that a dump

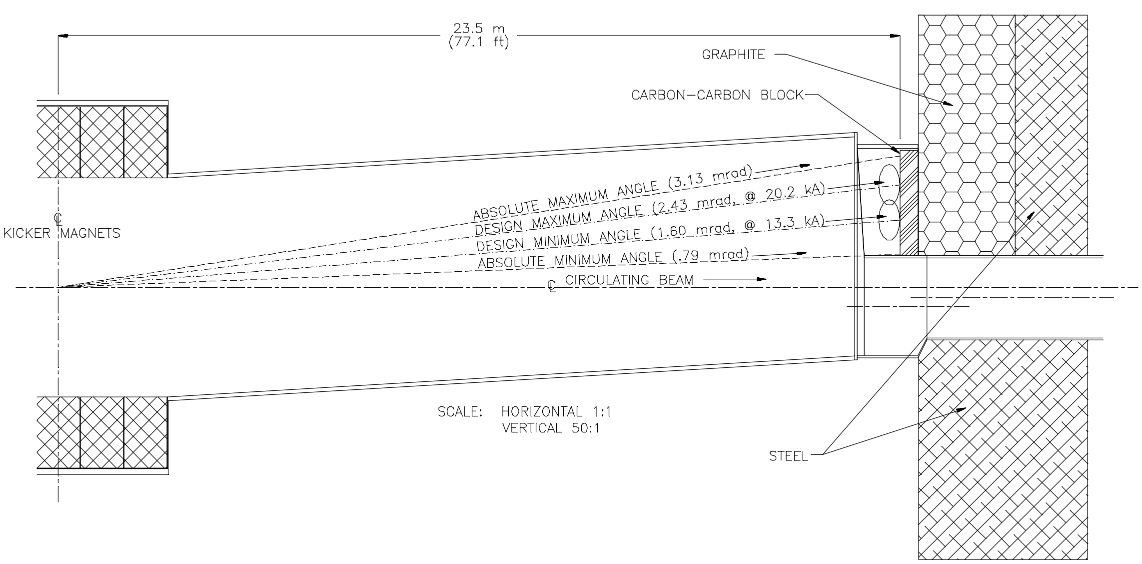

Fig. 6-3. Exaggerated plan view of dump geometry showing beam spots corresponding to acceptance aperture on dump face.

window would not crack due to thermal shock at the design intensity in worst case conditions. For this reason, it was decided to forego a window design by making the first element of the dump absorber a stress resistant graphite composite known as carbon-carbon (C-C), placed inside the vacuum chamber. This material is designed for Tokamak walls and missile tips, and is essentially impervious to thermal shock.

A diagram of the dump proper is shown in Fig. 6-4. As shown, the first element encountered by the extracted beam will be the C-C block, then the vacuum window, ordinary graphite and steel. Since the C-C block out-gasses to some extent, sputter-ion vacuum pumps must be employed to keep the vacuum in the ring sufficiently low. Estimates of the thermal stresses in the various materials of the dump give an adequate margin of safety against cracking and erosion of the C-C material at the design intensity.

Also shown in Fig. 6-4 is the aperture of the dump. At full energy, the circulating beam center line will be displaced horizontally from the physical center of the dump beam tube, so that the ring aperture at the dump is limited to 16.5 mm. This distance corresponds to the 6σ referred to previously. At injection energy, where apertures are tightest, a horizontal orbit bump can displace the beam center line to the physical center of the dump aperture which will then yield over 8.5σ at this location.

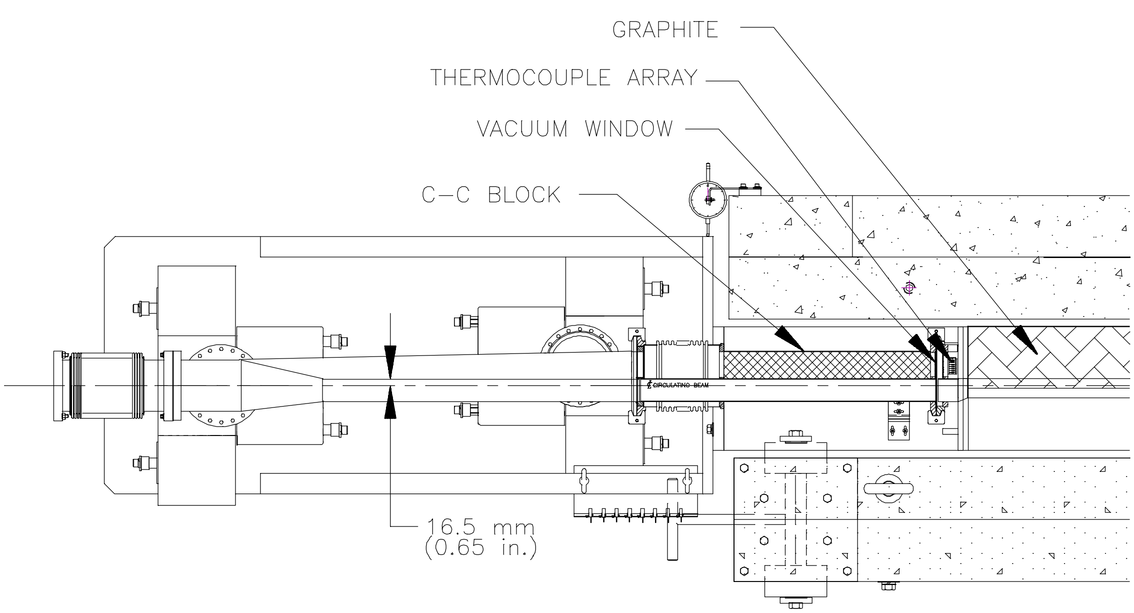

Fig. 6-4. Beam dump absorber details.

Although the dump design described here has a significant margin of safety at the design intensity, it is not clear whether the current design will be adequate for substantially upgraded beam intensities, especially as regards energy deposition in Q4 from secondaries emerging from the dump. Possible upgrades to the internal dump would include vertically deflecting sweeping magnets to increase dispersion of the bunches and a special Q4 magnet with a “liner.” Nothing in the current system precludes a future upgrade to a full extraction system to an external dump. Such a system would require a stronger kicker system, the addition of a septum magnet system in place of the current internal dump, and a special Q4 cryostat containing an aperture through which the beam could pass en route to an external dump.