iii. Operation

The mode of operation proposed here is based on the assumption that the conditions in RHIC represent the standard of reference for all activities. In a setup procedure, RHIC is made ready for filling and then kept stationary in that state until it is filled. In most filling scenarios, with the exception of the switching magnet, all magnets in the ATR are excited and remain stationary. The ATR is designed to transport particles with rigidities up to 100 T·m. The nominal design calls for injection into RHIC at 97.5 T·m. For transport of gold ions, the rigidity of the line upstream of the stripping foil must be increased by a factor of 79/77, since the charge state is increased when the last two electrons are stripped by the foil. The ATR has a window of spin transparency for polarized protons at $\gamma = 26.75$ ($p = 25.38$ GeV/c) which is sufficiently above transition in RHIC ($\gamma_T = 22.89$).

When used for filling RHIC the AGS may accelerate trains of from 1 to 12 bunches. Just prior to the events leading to extraction, the AGS closed-orbit control system is set to hold the circumference of the closed orbit at $4/19-\delta$ of the circumference of the injection orbit in RHIC (4/19 is the ratio between the circumferences of the reference orbits, δ is a small number, yet to be determined). The acceleration continues and the rf frequency keeps increasing until its sixth harmonic approaches the rf frequency in RHIC. When the difference has become small enough, a phase-locking loop between the two rf systems takes over from the radial position loop as controller of the AGS rf frequency and fixes it at exactly the 1/6 sub-harmonic of the frequency in RHIC with predetermined relative phases of the bunches in the two rings. The bunch that is to be extracted from the AGS must arrive in RHIC trailing the previous one by a predetermined number of RHIC buckets.

After phase-lock has been achieved, acceleration in the AGS continues, and the closed orbit begins to expand because the guiding field keeps increasing while the rf frequency is fixed. The motion of the closed orbit is monitored by the BPM (beam position monitor). When the orbit reaches the extraction orbit as indicated by the BPM, the acceleration is stopped by blocking further changes in the guiding field. The beam has now the correct extraction energy to within a tolerance that is determined by the resolution of the BPM and the local value of the dispersion function of the AGS. At that moment the

phase of the AGS rf relative to that of RHIC is jumped so as to place stationary buckets around the bunches, and the rf voltage is adjusted to preserve the match between bucket and bunch. These measures help to prevent dilution of the bunches in synchrotron phase space. It may be useful to reduce the rate of acceleration and the stable phase angle during these operations in order to lend

them a measure of adiabaticity and to reduce the changes in the guiding field that are associated with changes in the ($\dot{B}$ driven) eddy current distribution.

The AGS functions as a storage ring from this point onwards. The bunches in it have the proper synchronous energy and circulate around on the proper extraction orbit, the last bunch in approximately proper phase relationship to the charge distribution in the ring to be filled. Any remaining small phase error is now corrected by adiabatic adjustment. In the case of protons, bunch rotation in the AGS is required to reduce the bunch length by a factor of ~1.8 and achieve voltage matching with RHIC.

With its phase now as correct as it can be made to be, the bunch keeps circulating until its transfer to RHIC is initiated by excitation of the extraction and injection kickers. This is triggered by coincidence circuitry that produces a signal only when the last bunches of the bunch trains in each ring pass through specific azimuthal positions simultaneously. The waiting period may last up to 19 revolution periods in the AGS and up to 4 in RHIC, thus up to about 51 µsec, which time represents a `superperiod' in the AGS/RHIC cycle. The excitation of the extraction kicker in the AGS drives its last bunch into the transfer line, without disturbing the remaining ones. The extracted bunch finds the injection kicker in RHIC properly excited when it arrives there and becomes the last bunch of the train circulating in RHIC. The phase relationship between the last bunches in the two rings is now destroyed, since the new last bunch in the AGS is passing one AGS bucket spacing earlier than the previous one, while the next empty bucket in RHIC is passing three or, on day-one, six RHIC bucket spacings later than the previous one. That relationship must be restored before the next transfer can take place. The bunches in the AGS are shifted later in time by one AGS bucket spacing plus the appropriate number of RHIC bucket spacings by manipulation of the AGS rf frequency. This adjustment requires a time interval of the order of 20 msec prior to the next bunch transfer, the recharging times of the kicker power supplies and aperture considerations in the AGS imposing a practical lower limit. A limit on extraction frequency has been set at 30 Hz by hardware considerations. The tolerance on the relative constancy of the guiding fields in the two rings during this process is of the same order as that on the relative synchronous energies, i.e., a few 10^{-5}.

When the AGS has been emptied of its bunches in this manner, it returns for repeated acceleration cycles until all but a few of 60 (later 120) rf buckets in RHIC are filled. The AGS cycle time is about 2 seconds, and 19 cycles of 3 ion bunches each would fill 60 RHIC buckets in one ring. In fact, a gap of about 1 μsec will be left in the circulating beam (omitting 4 of 60 bunches) to facilitate the rise of the RHIC beam dump kicker magnet system.