NEW RADIATION HAZARDS AT THE K500 CYCLOTRON*

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Abstract

The new radiation hazards of the K500 cyclotron are discussed. With proper accelerator design, they can be minimized.

Introduction

The new generation of heavy ion cyclotrons and ion sources, for example the K500 at MSU, has opened up new regions of projectile masses, energies, and intensities. These new acceleration regimes can produce some interesting and new radiation hazards. Plans to minimize these can be easily implemented at an early stage of cyclotron construction. In the following sections the new radiation hazards detected at the K500 cyclotron are discussed.

Central Region Activation

After initial start up of the K500 cyclotron, it was soon discovered that the cyclotron central region could become very radioactive. (see Fig. 1)

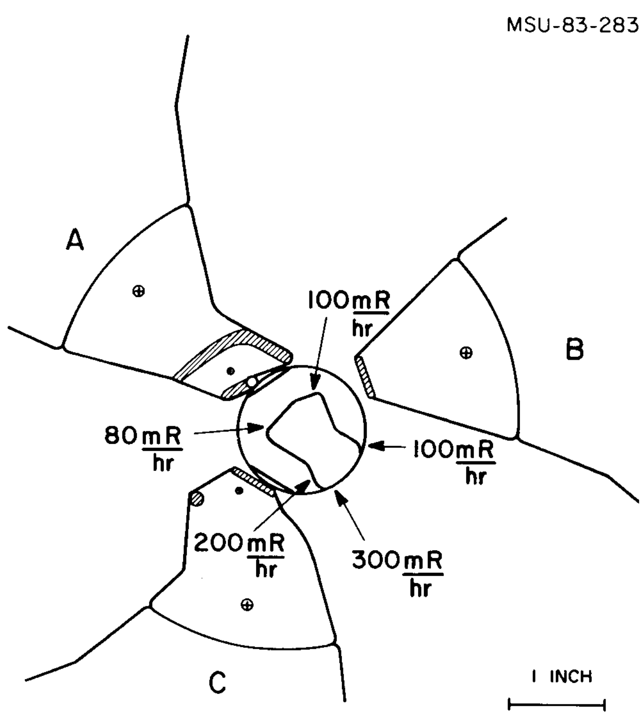

Fig. 1. A median plane cross sectional view of the central region of the K500 superconducting cyclotron is shown. The dees are labeled A, B and C. The ion source is located within the 1-3/8" diameter circle at the center with the source slit opposite of the puller located in dee A. The arrows are indicating measured radiation levels (mrem/hr.) at contact with an ionization chamber after a run with a 30 MeV/u $^{14}N^{4+}$ beam.

Calculations and additional observations discovered that the process was due to particles from the acceleration of the heavy ion beam, stripped of an electron when they collided with the acceleration chamber background gas molecules.[1] Figure 2 shows the ion charge state for various atomic masses that can cause activation as a function of cyclotron size (K).

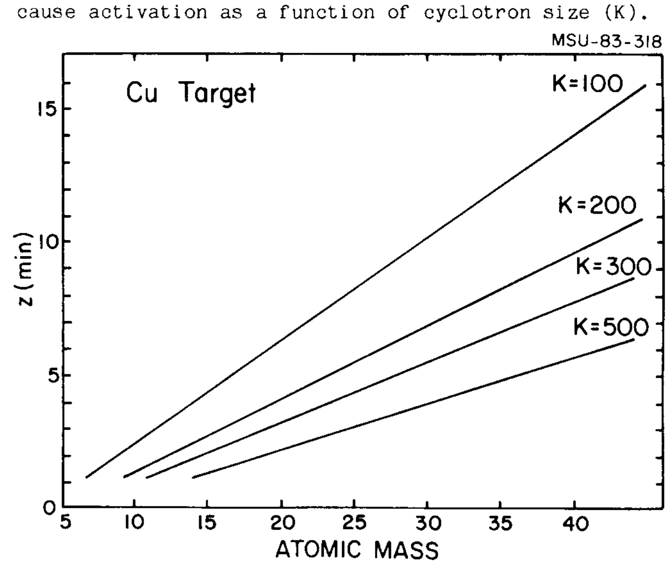

Fig. 2. The minimum charge state (Z), when stripped to (Z+1) that can activate the cyclotron central region, is shown for various cyclotron K factors (MeV) as a function of atomic number with copper used for the Coulomb barrier.

The theoretical results indicates that the K500 cyclotron at Michigan State University is the first heavy ion cyclotron to operate extensively within the energy band for this process.

The use of internal Penning ion source exacerbated operations in two ways. First, the source cathodes had to be changed on a few hour interval, thereby causing operations personnel to be exposed to the activated source head. Second, the unused ion source gas leaked into the acceleration chamber, thus being a major contributor to the acceleration chamber background pressure. This caused the accelerated beam to be stripped. With the installation of the external ECR ion source, both problems have been solved. That is, the central region parts need very little maintenance and the pressure in the accelerator chamber is approximately 5 times lower.

Induced α Activity with the K500

In 1983, the Oak Ridge Ischronous Cyclotron (ORIC) was contaminated by the α emitters ^{210}Po and ^{208}Po.[2] Subsequent studies discovered that this activity was produced by the acceleration of a heavy ion beam that exceeded the fusion barrier on tantalum and the sum of the target and projectile atomic masses equalled the mass numbers of heavy isotopes which emit α particles. The accelerator extraction septum was made of tantulum.

We have now studied this activation problem for the K500 cyclotron, preoperationally with respect to α emitter production. The theoretical results of the study are summarized in Fig. 3. The shaded area represents conditions where the energy is above the Coulomb barrier (5 MeV/u) and the compound nucleus contains sufficient neutrons and protons to produce nuclei known to be radioactive α-particle emitters. This shaded area is now accessible with charge states available from the ECR ion source when a tantulum target is used.

In our first experimental studies, a Pb foil stack (stopping total thickness) was irradiated by $^{40}Ar^{11+}$ having 30 MeV per nucleon. The foil stack was studied for alpha emitters using a silicon detector the day

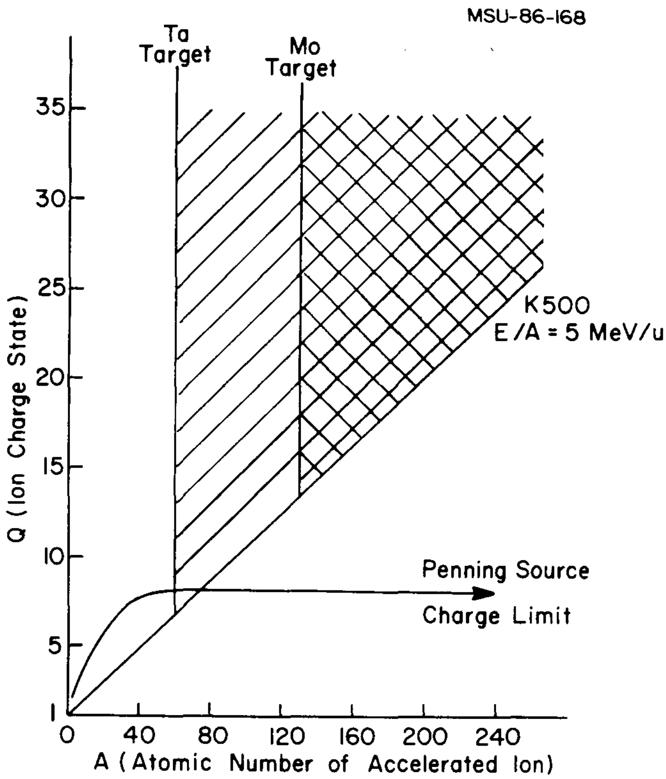

Fig. 3. The accelerated ion charge state versus its atomic number is plotted for the K500 cyclotron. The shaded area is where induced α activity can occur within the accelerator. The normally obtained Penning ion source charges are below this shaded area.

after irradiation. Alpha particles were observed with a peak in the yield around 10 MeV per nucleon. Argon induced reactions at 15 MeV/u on Au and Bi are known[2] to produce Po isotopes, some of which decay by relatively high energy α emission (>7 MeV).

If molybdenum is substituted for tantalum as the target, the region in Fig. 3 for induced α activity is reduced (double shaded area). The hazard then does not exist for projectile masses below A=130 (in contrast to A=60 for Ta). Therefore molybdenum has been substituted for tungsten in the beam probes and the deflector septum. Studies to use carbon for the deflector septum are also planned. Septa made from tungsten previously used in the K500 were observed to have tens of mrem/hr beta and gamma exposure rates on contact and within a few hours of accelerator shutdown, reaching 1/10 these rates only after several weeks. We have two interchangeable sets of electrostatic deflectors to minimize personnel exposure.

Radioactive Beam Production

Radioactive beams are now being produced by the K500 cyclotron. The process of making the radioactive beam involves the stripping of an intense primary beam to a higher charge state. This stripped beam is then lost in the accelerator and is assumed to be deposited on the copper dees. The primary beam is presently 35 MeV per nucleon ^{18}O and its highest intensity has been 1.4 eμA. The ECR ion source can deliver a much higher beam intensity.

However, the question of activating the cyclotron interior beyond safe levels for maintenance has resulted in activation studies on Cu foils. A stack of six copper foils, each 10 mils thick, were irradiated by a 40 MeV/u $^{12}C^{5+}$beam. The collected charge was 253 microcoulombs. The production of radiation was peaked on the foils located between 10 and 20 MeV/nucleon. The foil stack is self-shielding to a significant extent and the radiation is mainly beta.

Figure 4 is the radiation decay curve measured by an ion chamber located 6" above the copper foil. Such data were used to estimate the radiation intensity at the center of the cyclotron, 50 hrs after a 24 hour bombardment with .2pμA of 40 MeV/u carbon beam. The result is 30 mrem/hr. Studies of this problem are continuing.

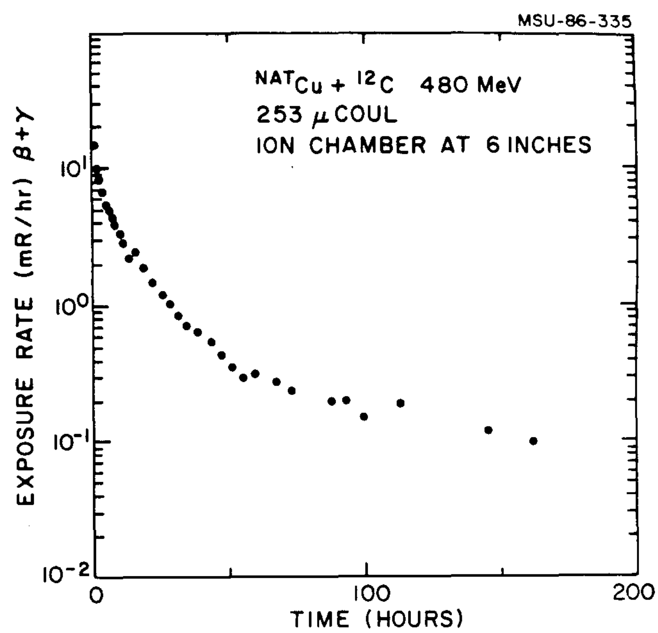

Fig. 4. The decay curve for the irradiation of a copper foil with a 40 MeV/u carbon beam and a total charge collected of 253 microcoulombs.

The isotopes that can be expected[4] to be produced with high cross sections in the reaction are ^{51}Cr(28d), ^{54}Mn(313d), ^{57}Co(272d), ^{58}Co(71d), ^{61}Cu(3.4hr), ^{62}Zn(38m) and ^{65}Zn(244d).

X-Rays

X-rays, primarily bremsstrahlung, are produced by residual electrons in the beam chamber accelerated by the electric field of the dees and the electrostatic deflectors. In the K500, deflector x-rays are completely shielded by the cryostat and yoke of the magnet. The same is true of the dees, except for a few windows. We have observed x-rays intensities as high as 100 mrem/hour outside a view port with dee voltage of 80 kV (peak). Since a window subtends a small solid angle at the x-ray source, the x-ray beam is narrow and easy to avoid. This hazard is therefore minimal due to the self-shielding nature of the K500 magnet.

With the operation of a large, 2 stage ECR ion source at NSCL, a new x-ray radiation hazard has been introduced. The origin of the x-ray emission seems to be bremsstralung production by electron cyclotron resonance heated electrons in the plasma colliding with the walls. The emission occurs dominantly in the low pressure main stage - with peaks axially at the ends of the chamber and radially along the plasma flutes centered on the hexapole magnet poles. The X-ray energy endpoint has been found to be above 150 keV. For normal operation, the unshielded radial emission approximately 10 inches from the plasma is 0.5 to 1 rem/hour. The x-ray production is proportional to main stage volume - the above rate being somewhat more than the smaller volume LBL ECR source[5], but much less than that reported for the large source ECREVIS.[6] In addition, the rate has a weak positive dependence on injected microwave power, increasing as the size of the ECR zone is decreased at fixed microwave power, and is inversely proportional to main stage pressure.

It is fortunate that the best high charge stage performance of the ion source does not occur at maximum x-ray emission levels. Nevertheless the nominal rate mentioned previously must be shielded. In the NSCL source the hexapole magnet bars, copper circular coils and cylindrical iron return yoke (with end caps) all serve as the main x-ray shield. The remaining emission comes from radial ports on the plasma chamber - these are shielded by filling unused portions with copper plugs, and externally with lead screens.

Recent production of tantalum ions in the source by the radial insertion of a .010" Ta wire into the plasma, did result in 18 rem/hour x-ray rates at the insertion point. Future production of metal ions by this technique will have to be carefully shielded.

Conclusion

The operation of the K500 cyclotron has uncovered some new radiation hazards. These hazards can be easily reduced and the machine safely operated.

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