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Conceptual design of the Booster beam dump

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I. Function/Location of the Beam Dump

The beam dump envisaged for the Booster serves two conceptually distinct functions. The first function is to intercept as much as possible of the beam loss during normal Booster operation. Confining loss to one well-shielded location minimizes activation and radiation damage to machine and subsystem components interior to the Booster tunnel. This functionality is that of the AGS "beam catcher".

The second function is the traditional purpose of a dump: a place to put the beam in (a) emergency situations and (b) periods of Booster studies where injection into the AGS is impossible or undesirable. Some consideration was given to an external dump. An external dump has two potential advantages when compared to an internal (interior to the tunnel) dump: (1) the "hot" (radioactive) dump is removed from the tunnel thereby reducing personnel exposure, and, (2) the integrity of the dump material is easier to assure since the beam can be "blown up" before intercepting the dump face. The disadvantage to an external dump is considerable expense; extraction equipment, special beam pipes, excavation, etc. is all necessary. However, when the total annual energy loss on the beam dump is compared to the loss on the internal catcher(1), the numbers are the same. Since this implies that a hot-spot is unavoidable, it was decided to design an internal dump to serve both the traditional and "catcher" functionalities.

The beam dump will be located in the "D" superperiod as shown schematically in Fig. 1. Upstream of the dump is a dump kicker which will be triggered during studies (and, presumably, by certain anomalous conditions) to deflect the beam to the dump face (or "lip" as shown in the next section). The kick is horizontal in the ring-center direction and is of ~ 1 μsec duration. This rise time enables the three Booster bunches to be spread out horizontally on the face of the dump.

II. PHYSICAL DESCRIPTION OF THE DUMP AREA

A beam dump can be thought of as being divided into inner and outer regions, where the purpose of the inner region is to absorb the (majority of) the beam energy and the outer region serves to attenuate both instantaneous and induced radioactivity to an acceptable level.

Figure 2 shows an idealized sketch of the cross-section of the energy absorbing part of the dump, which consists of a cylinder surrounding the vacuum pipe and a "lip"(interior to the vacuum on the low-momentum side) which "catches" off-momentum particles and onto which the beam is deflected by the kicker. For the numerical calculations described in the next section of this note, we have taken the material to be an iron-nickel chromium steel alloy called Incoloy, although other steel alloys may be preferable as discussed in Section IV.(2). Figure 3 shows a cross-section of the tunnel in the dump area. On both sides of the Incoloy cylinder (whose supports are not shown in Figure 3) are 20cm thick marble ($CaCO_3$ with p=2.7g/cc) piers. The pier on the right hand side of Figure 3 (machine center) could, in fact, be composed of any convenient material. The choice of marble has importance for the pier on the left hand side of Figure 3. This pier faces the region where people will be during Booster-off periods. Marble was chosen because it has low induced radioactivity as discussed further in Section V below. The roof sketched n Figure 3 shows a 20cm. Fe slab in addition to 20cm. of marble. Only the 20cm. of marble has been considered in Booster calculations as concerns instantaneous dose rates exterior to the tunnel(3). The Fe slab was added "because there was room". Since the berm top over the dump area is one of two locations expected to dominate both on-site and site boundary skyshine, including this slab would be prudent if practicable.

A sketch showing the beam dump area along the beam direction is shown in Figure 4. The location is in one of the long (3.7) Booster straight sections[4]. Note that the marble shielding extends both upstream and downstream of the steel cylinder. An additional marble pier is shown in the downstream part of the dump straight section to avoid line of sight exposure between personnel and the steel and to prevent people from physically approaching the steel. The dump has been confined to one side of the Booster tunnel to avoid interference with the magnet transport system.

III. ENERGY DEPOSITION CALCULATIONS

Energy deposition calculations were made using the computer code CASIM[5]. The beam is assumed to uniformly distributed on the face of the dump lip over an area 2.2cm. in X by 0.8cm. in Y[6] which begins at the X-edge of the lip and is centered in Y. (In Figure 2, X is horizontal and Y is vertical). Calculations have been done only for the "worst case" Booster running conditions, protons at the full (1.5 GeV) energy. With the beam incident as described, about 12% of the incident energy escapes the steel dump. The energy is divided equally between energy escaping laterally and energy which escapes from the "hole" in the middle of the dump. The latter category is dominantly out-scattered protons.

Energy deposition densities were calculated in the Incoloy steel by dividing the steel into 45 regions in the Y, Y plane and 12 regions in Z (beam direction). Each Z bin was taken as 8 cm. in length. The X, Y regions are shown in Figure 5. The "hot spot" is the first Z bin of Region No. 1, which has the same transverse area as the beam. This volume obtains 1.1×10^{-3} GeV per gram per proton. A full beam dump of 6×10^{13} protons raises the temperature of this region by 21°C.

IV. HEAT TRANSPORT CALCULATIONS

Energy deposition calculations serve as input to heat transport calculations. For calculational convenience, the 45 regions shown in Figure 5 were mapped onto 15 regions in a rectangular geometry as shown in Figure 6. The mapping preserved the energy density in the "hot spot", the total energy in the dump, and the transverse area of the dump. (The division of region No. 6 in Figure 6 into two parts was done for the purpose of exploring possible positions of cooling channels as discussed below.)

Heat transport calculations were done using the ORNL HEATING5 Code[7]. Although the most severe requirement for the dump is anticipated to be beam studies at 1.5×10^{13} 1.5 GeV protons per second[6], it was decided to design the dump to withstand the full 6×10^{13}p/sec rate. Two-dimensional calculations were done for various Z slices as described in the last section; the second Z slice turns out to be the worst case.

Referring to Figure 6, the first calculations were done assuming cooling by radiation and natural convection on the outer boundaries and by radiative transfer across the vacuum gap. For natural convection, the simplified formula of Welty were used[8]. For radiation, an emissivity of 0.35 was assumed[9]. Only steady-state (infinite time) calculations were done, in which case the only material parameter which enters is the thermal conductivity. For Incoloy, the thermal conductivity is 0.115 Joule/cm^2/sec/(°C/cm)[10].

Without water cooling, the maximum temperature is found to be 1357°C. Since the melting point of Incoloy is 1385°C, water cooling is required. The region shown in Figure 6 labeled 6B was replaced by a region of constant temperature at 30°C, which should be achievable with an inlet temperature of 25°C and a flow rate of ~ 50 cm/sec. With this assumption, the maximum temperatures reduced to 1050°C. If the cooling channel is taken as region 6A, closer to the hot spot, the maximum temperature decreased to 897°C.

Although this result might well be satisfactory, a lower operating temperature would be desirable. Rather than explore additional cooling channels, other materials were considered. Incoloy has a very poor thermal conductivity in comparison with many heat-resistant steels. Two appealing candidates would appear to be AISI types 430 and 502[11] which have better thermal conductivities than Incoloy by factors of 2.25 and 3.0 respectively. Reference (11) also records a "maximum temperature without excessive scaling" for these materials - 843°C for type 430 and 621°C for type 502. Although the value of this number is not known for Incoloy, Incoloy is known to be highly resistant to scaling, so we have (somewhat arbitrarily) assigned the scalling temperature as 1285°C, only 100°C below the melting point.

The calculations described above for Incoloy were repeated for types 430 and 502. For both locations of the cooling channel, type 430 was superior to the other two candidates in comparing the maximum temperature to the "scaling temperature". For the cooling channel in location 6A, type 430 reaches 477°C, 56.6% of the scaling temperature where as Incoloy reaches 69.8% of its (optimistically?) assigned scaling temperature.

Exterior cooling was also considered. With broad areas (the middle third) of the top, bottom, and right hand side of Figure 6 assigned to 30°C boundary condition, Incoloy reached 1075°C and type 430 608°C; the latter value possibly being acceptable.

The exact choice of materials is left to the detailed design where other factors (cost, availability, etc.) must also be considered. The conclusion of the calculations performed here is that water cooling is required for the dump lip to survive the full beam intensity and that attention should be given to the choice of materials.

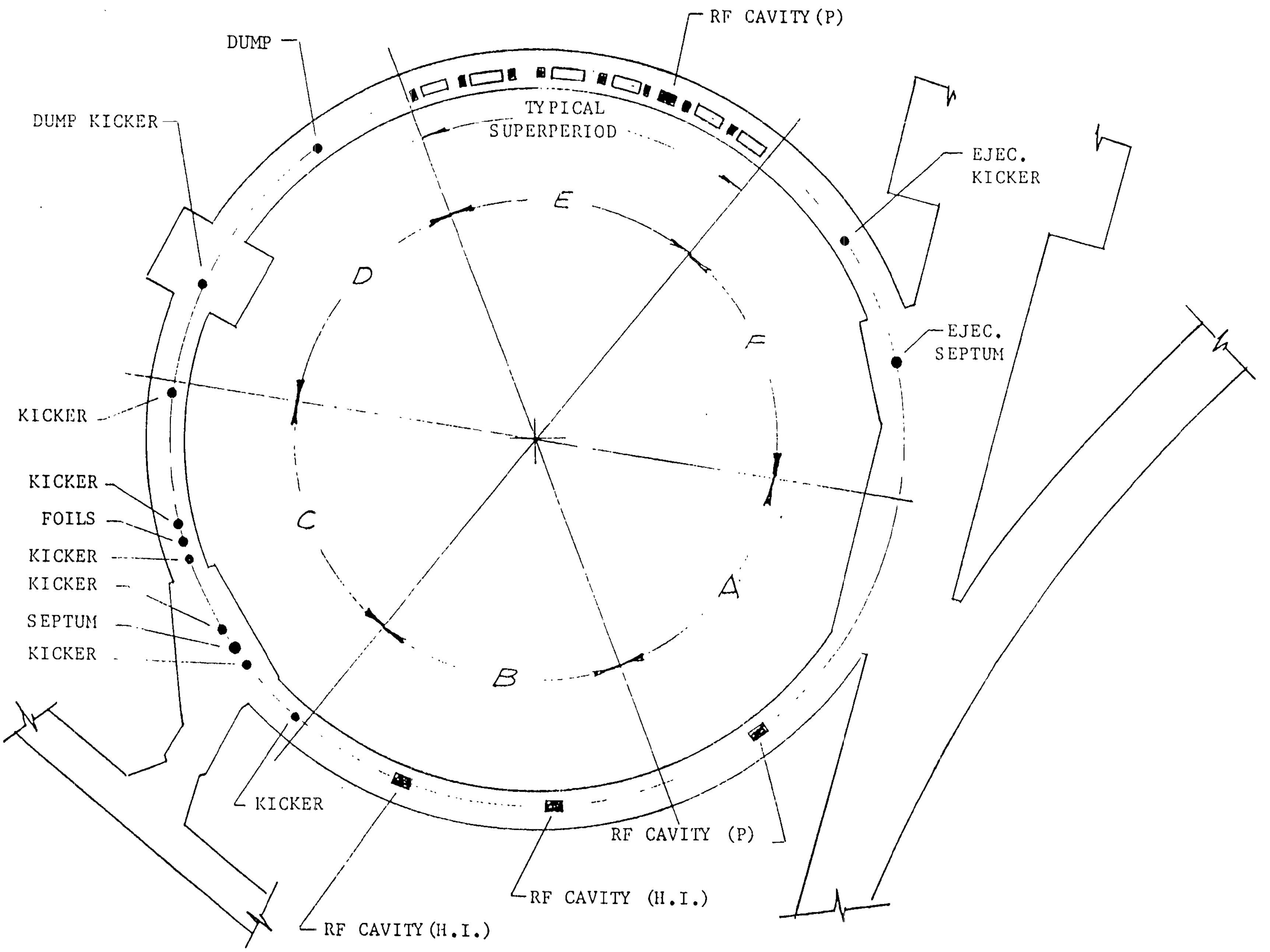
V. INDUCED RADIOACTIVITY

Calculations of induced radioactivity in the beam dump area have been described n a previous note[12]. The results are presented here also for completeness. Briefly, the method employs the following procedures. First, CASIM is used to calculate star densities (hadron interaction densities) in the beam dump area material. From this number the irradiating flux can be obtained. Finally, tables and formula taken from Barbier[13] can then be used to determine the induced activity, although some approximations are necessary which are described in reference 12. Table I below shows the activity as a function of cooling time at a distance of 1 foot from the marble pier near the beginning (in Z) of the dump. Irradiation at 1.5 x $10^{(13)}$ p/sec for 30 days has been assumed. If the marble pier were not present, the activity at 1 foot from the dump steel would be 3.3 Rem/hr instead of the 196 mRem/hr at this distance of approach shown in Table I. As shown in the "Danger Parameter" graphs in Barbier, marble has low levels of induced activity which make it an excellent choice for the "shielding" portion of the dump.

Table I

ACTIVITY AT 1 FOOT FROM MARBLE PIER IN MRAD/HR

TC (days)	Marble	Punch-Through	Total
.01 (15 min)	180	16	196
0.1	47	10	57
1.0	16	7	23
10.0	1.7	3	4.7



LOCATION OF RING MAGNETS AND SPECIAL COMPONENTS Fig. 1

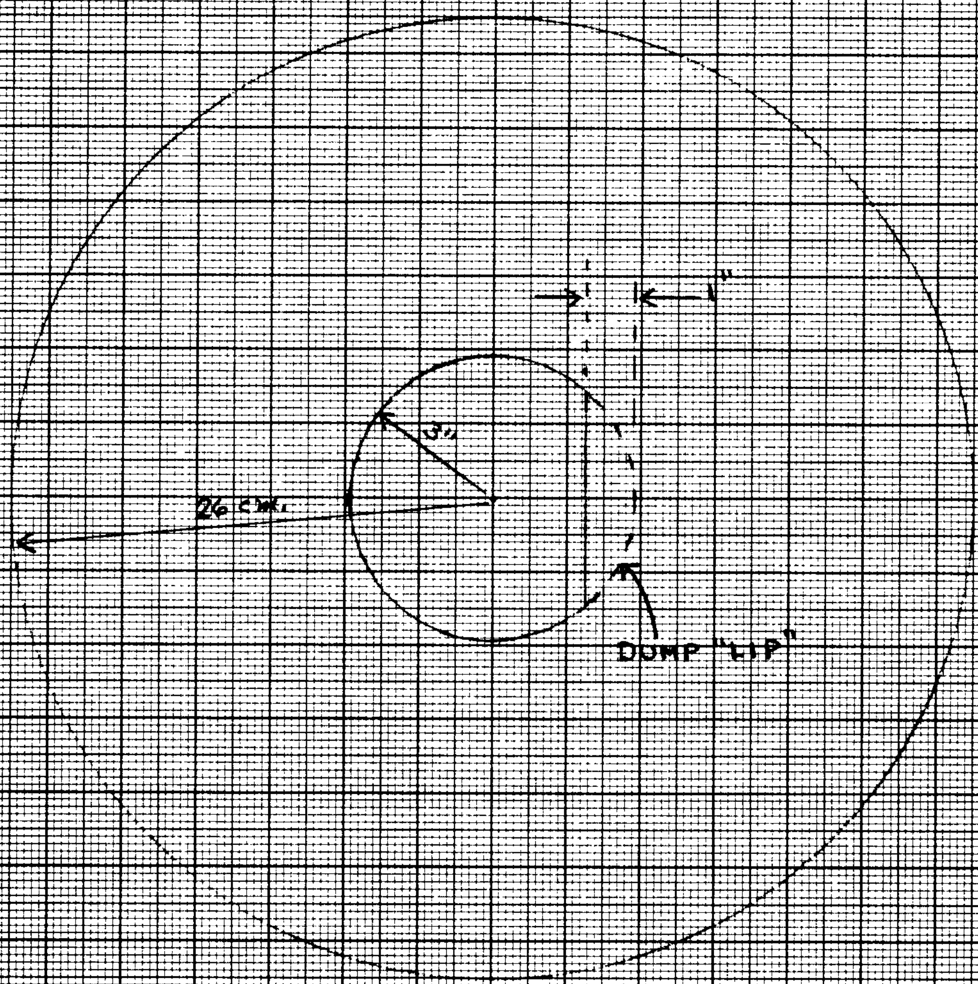


Fig. 2. CROSS SECTION OF DUMP SCALE 4:1

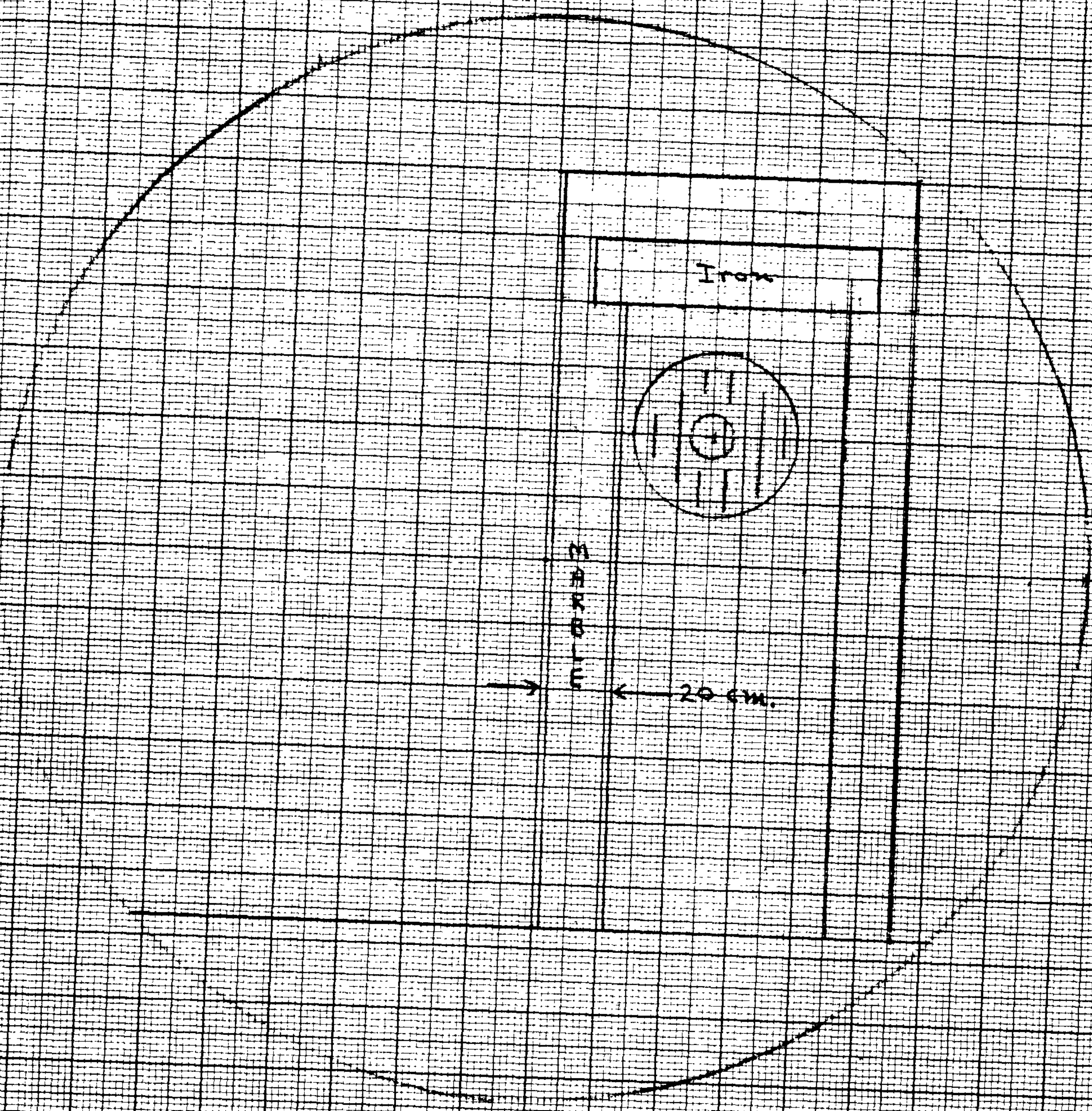


Fig. 3 CROSS SECTION OF TUNNEL IN DUMP AREA
SCALE 20:1

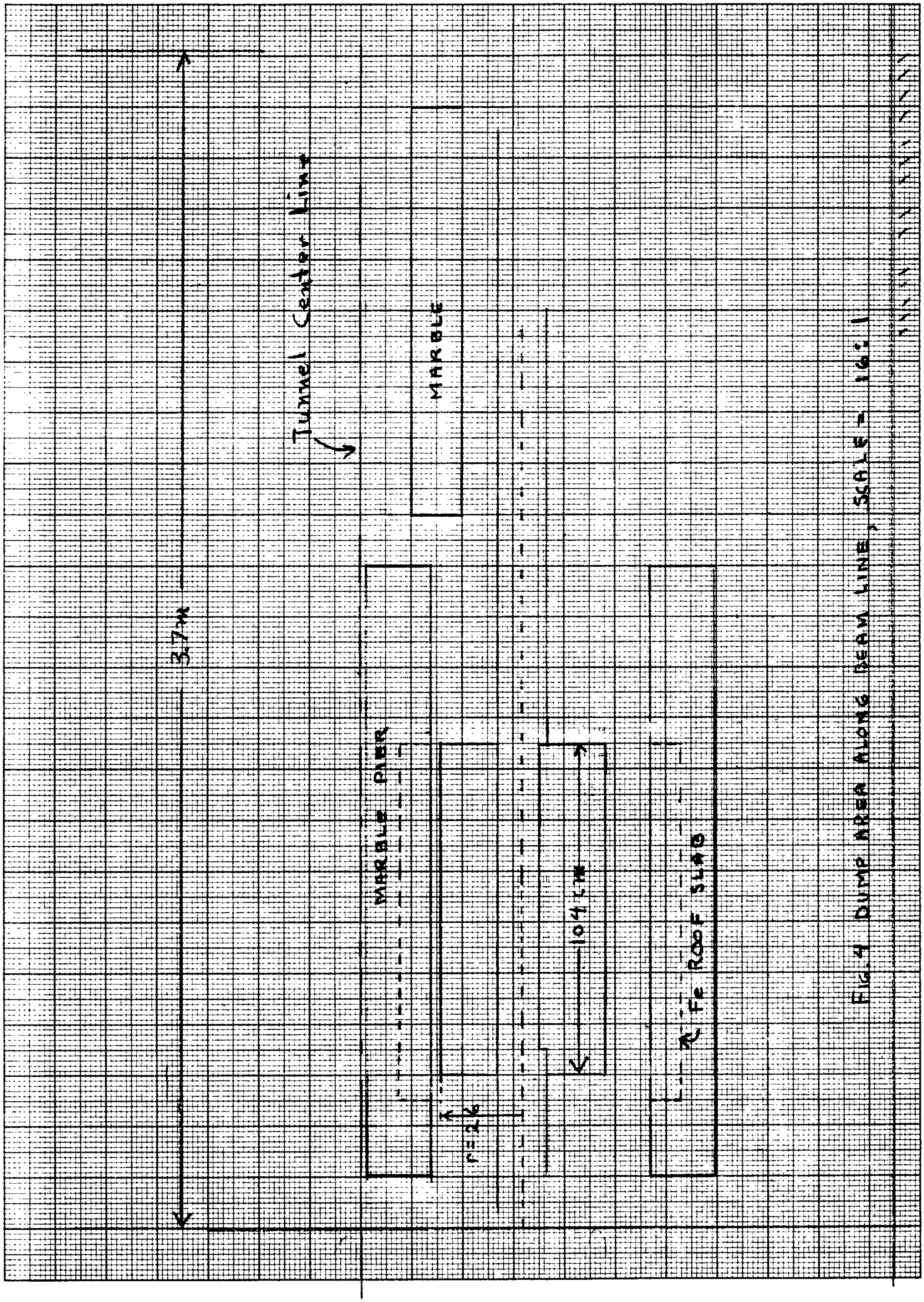


FIG. 4 DUMP AREA ALONG BEAM LINE, SCALE = 16:1

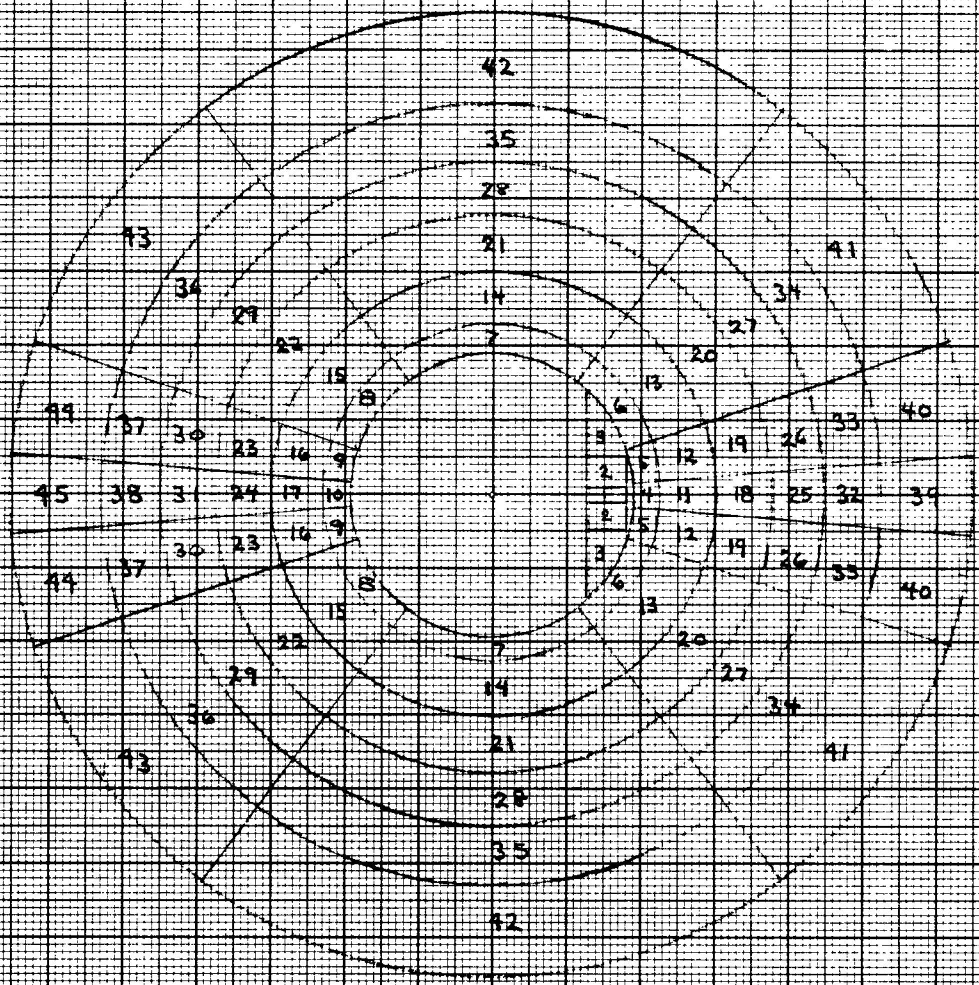


Fig. 5 TRANSVERSE ENERGY DEPOSITION DENSITY REGIONS

SCALE 4:1

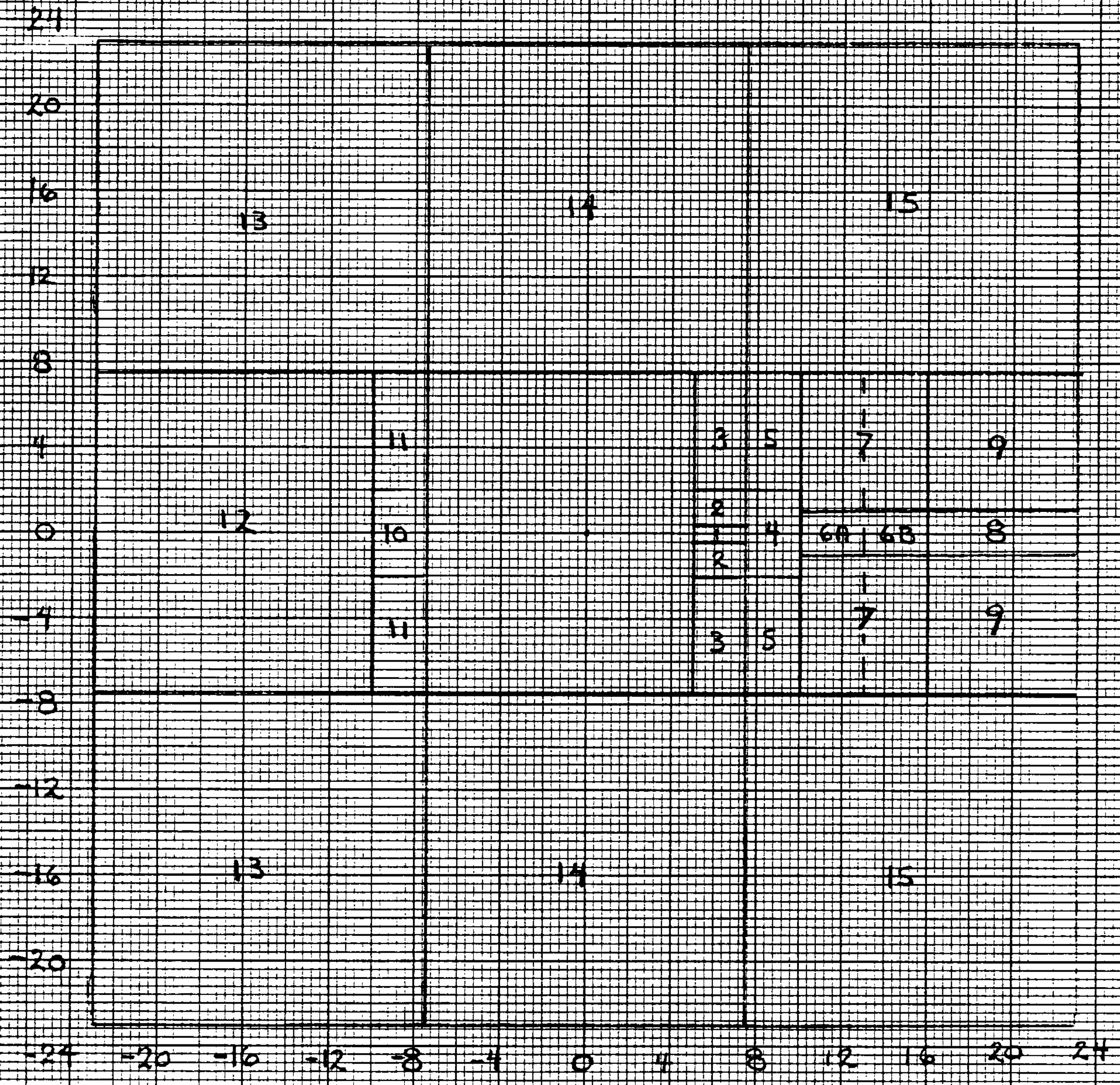


FIG. 6 RECTANGULAR GRID USED FOR HEAT TRANSPORT CALCULATIONS

ACKNOWLEDGMENTS

The author expresses gratitude for useful conversations with Y. Y. Lee and W. Leonhardt. Thanks also to Judith Colman of DNE who made the HEATINGS computer code available.

REFERENCES AND FOOTNOTES

1. Y.Y. Lee, private communication. Dump losses will be dominated by full energy proton studies at 1.5 x 10^{13} p/sec which will be scheduled 1/3 of the scheduled days and 1/3 of the scheduled hours per day. By contrast, catcher losses are dominated by continuous loss of 20% of the 6 x 10^{13} p/sec beam at 200 MeV. (Both of these numbers are over-estimates which ignore the lower intensity running periods of heavy ion and polarized proton physics)

2. Experience in the neutrino target area of the AGS has shown Incoloy Alloy 800 to be highly resistant to radiation damage and to "scaling" at high temperatures.

3. W. R. Casey, "Additional Booster shielding Calculations", Booster Tech. Note No. 93, Sept., 1987.

4. The dump is located in Section D6 and the dump kicker in Section D3 in Figure 2-1 of the Booster Design Manual.

5. A Van Ginnekin, "CASIM. Program to Simulate Hadronic Cascades in Bulk Matter", Fermilab FN-272, 1975.

   See also A. J. Stevens, "Air Activation in the Booster tunnel", Booster Tech. Note No. 86, August 1987.

6. Y. Y . Lee, private communication.

7. W. D. Turner, D.C. Elrod, I. I. Siman-Tov, "HEATING5 - An IBM Heat Conduction Program", ORNL/CSD/TM-15, 1977.

8. J. R. Welty, "Engineering Heat Transfer", John Wiley & Sons, 1979, p.253.

9. Ibid, p. 444, 445. The emissivily depends greatly on surface conditions with the range 0.2-0.5 being common for steels.

10. W. Leonhardt, private communication.

11. T. Lyman, Ed., "ASM Metals Handbook, Edition 8", Vol. 1, 1961, pp.422-423.

12. A. J. Stevens, "Booster Soil, Component, and Water Activation", AD Booster Tech. Note No. 89, Sept. 1, 1987.

13. M. Barbier, "Induced Radioactivity", North-Holland, 1969; Chap. 1, Section 8 and Appendix B.