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ABSTRACT

The 200 BeV proton accelerator studied by the Lawrence Radiation Laboratory is described, with special attention given to those aspects of the design relating to radiation problems. Various radiation problems are compared with those already encountered at presently operating accelerators. The primary use of external beams greatly facilitates machine maintenance and operation. Muon shielding is discussed in some detail.

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INTRODUCTION

The AEC has recommended[1] construction of a 200-BeV proton accelerator, in accordance with technical specifications developed by LRL. This technical information is contained in an LRL design report[2] on the 200-BeV accelerator study dated June 1965. It was realized from the beginning of the study that radiation problems would or could be far more severe than has been experienced with present accelerators and that considerable interaction would exist between the management of radiation problems and machine operation, including maintenance.

200 BeV ACCELERATOR FACILITY

Figure 1 is an artist's conception of the 200 BeV accelerator facility, including the various buildings and three experimental areas, and dominated by the main 200 BeV synchrotron ring structure, which is slightly less than 1 mile in diameter. Figure 2 shows the experimental areas in more detail. The acceleration cycle requires four accelerators in series, as listed in Table 1.

One sees from Table 2 that not only is the design energy some seven times that of the present strong-focusing proton synchrotrons at CERN and Brookhaven, but also the beam current is to be some 30 to 40 times as great. The 500 kW of average beam power should be compared with the present machines' 2 to 3 kW, since, in a crude sense, the quantity of radiation we must deal with is proportional to this power.

RADIATION PROBLEMS

At the beginning of the cycle of development of any type of accelerator, the main problem is getting any beam at all, and later to get enough beam to do physics experiments. Radiation problems can hardly be said to exist at this beginning stage, and accelerators were built with no shielding and they could be manually repaired as any other piece of machinery. Only with increasing beam intensities came radiation problems, so we are justified in calling them happy problems. For a given machine, an increase in beam intensity can change the radiation picture only by multiplying what was present at low intensity, since the physical processes are determined by the type and energy of the accelerated particle. However, this multiplication is important, since it can make undetected radiation levels detectable, detectable levels uncomfortable, and uncomfortable levels unbearable. This is one sense in which we can speak of radiation problems as being new. Another sense has to do with physical processes that are not present at lower-energy accelerators. Either a completely new type of radiation will appear or one that we are currently aware of will begin to be troublesome in the new higher-energy region. In Table 3, I've listed the various problems, with my opinions as to whether their influences and attendant control measures will be: Not New, or more of the same; Seminew, a significant increase over present effects and efforts; or New; all with reference to the present generation of proton synchrotrons.

DESIGN AND OPERATIONAL CONTROL POLICY VIS-A-VIS RADIATION

For the physics experimental program, for reasons having to do with high-energy particle kinematics, primary reliance is to be on use of external proton beams. This allows continued machine operation while experimental setups are being changed, and has the advantage from the radiation standpoint that most of the beam loss occurs outside the accelerator enclosure and in an experimental area where one can, presumably, deal with it more easily. With slow beam extraction, we estimate the extraction efficiency to be greater than 85%; as a matter of policy, when the internal target area is in use the interaction rate at an internal target will not be allowed to exceed 15% of the maximum possible rate. Therefore, radiation levels at the two external extraction areas and the internal area will be about the same.

With the above policy constraints the main ring can be divided into two classes: 95% of the circumference is a quiet area where maintenance can be carried out by unshielded workers; 5% of the circumference includes the three target areas, and unshielded workers generally cannot enter these areas. Table 4 lists the saturated γ fields at shutdown in these two areas. One component of these fields is from the concrete enclosure walls, in which ^{24}Na can be formed, and this component is fairly uniform throughout the enclosure. The other component is much greater on the open C side than on the yoke side or top and bottom of the magnet. In the target area, plugs can be inserted in the magnet open C side, and the concrete in the enclosure walls can be different from that in the quiet area.

MUONS--A NEW PROBLEM

With a proton beam intensity $\approx 10^{13}$ protons/sec, one can easily have a π meson beam intensity of $\approx 10^{9}$ π/sec down a secondary channel of well-defined momentum. Depending on several variables, a muon flux $\geqslant 10^{5}$ μ/cm^{2} sec can be achieved. Since a flux of ≈ 20 μ/cm^{2} sec corresponds to a radiation field of 2.5 mR/h, one will definitely have to provide μ shielding.

Figure 3 displays the difference in the shielding problems for strongly interacting particles and muons. We are here concerned with shielding in the straight-ahead direction, which is pertinent for the primary beam-disposal area. For SIP one sees, after the usual build-up curve, an exponential decay vs depth with a mean free path of some 130 g cm^{-2}. For an incident proton energy of 200 BeV, an equivalent mean free path for muons is some 6000 g cm^{-2}. At the shield thickness needed for SIP, 3000 g cm^{-2} or approximately 6000 lb ft^{-2}, the muon flux is some two orders of magnitude greater than that for the SIP. At present lower-energy synchrotrons this problem is less severe, since the equivalent mean free path for the muons is closer to that for the SIP, i. e., the μ-meson curve is steeper than the one shown in Fig. 3.

Since the μ is a lepton, we know that it cannot interact through the strong interaction. Therefore except for the small final portion of its range it will be near minimum ionization, and the RBE is certainly 1. However, most of the ionization caused by other particles that are encountered outside the shielding is from SIP's, and the various RBE's will be closer to 10. The problem is further complicated in that the μ beams will tend to be confined to smaller angular ranges about the forward direction than the SIP. Hence, the muons will probably have to be monitored separately from the other components of the radiation field.

Figure 2 shows the experimental areas and in particular the long external beam area J, with three target stations--switchyards. Figure 4 shows the final end stations in greater detail. To the left of the bending magnets one can see the small beam-dump area. The double snout extending to the left of this is the depleted uranium μ shield. If lead, iron, or some other lower-density material were used, the dimensions would be correspondingly greater.

Another miscellaneous number which has to do with the magnitude of the radiation survey and control job is that when the facility is being fully utilized there will be about 25 experimental beams totaling some 5 miles in length.

REFERENCES

1. Policy for National Action in the Field of High Energy Physics, U. S. Atomic Energy Commission, Washington, D. C., January 24, 1965. Also reprinted as part of Report on National Policy and Background Information, Joint Committee on Atomic Energy, Congress of the United States, February, 1965.

2. 200 BeV Accelerator Design Study, AEC Report UCRL-16000, Lawrence Radiation Laboratory, June 1965.

Table 1. The four accelerators used in series.

Accelerator type	Energy range
Cockcroft-Walton	0 - 3/4 MeV
Linac	3/4 - 200 MeV
Injector synchrotron	200 MeV - 8 BeV
Main synchrotron	8 BeV - 200 BeV

Table 2. Miscellaneous beam information.

Design intensity (200 BeV)	3×10^{13} protons/pulse
Maximum repetition rate at 200 BeV	1 pulse/2 sec
Maximum average beam power	500 kilowatts
Ultimate intensity (200 BeV)	1×10^{14} protons/pulse

Table 3. Radiation problems.

A. Beam loss--Where, when, cascade development, etc.--More

B. Beam disposal or dump--New, but special

C. Strongly interacting particle (SIP) shielding

  1. Transverse ring shielding--Not new
  2. External proton beam and secondary beam shielding--Seminew
  3. Skyshine--Not new

D. Weakly interacting particle shielding

  1. Muons--New (Range > shield thickness needed for SIP)

E. Induced radioactivity and remote handling

  1. Magnets and machine components--Seminew
  2. Concrete walls--New
  3. Air and water--New

F. Radiation damage--Seminew

Table 4. γ Fields at shutdown.

Position		Quiet area Magnet (mR/h)	^{24}Na in walls (0.3% boron) (mR/h)	Total (mR/h)
1 ft from coils		43	8	51
2 ft from coils		26	8	34
1 ft from yoke		0.2	8	8

	Target area Magnet (R/h)	Magnet (plugged) (mR/h)	Walls (0.3% boron) (mR/h)	Total (Plugs in magnets) (mR/h)
1 ft from coils	19.3	134	800	934
2 ft from coils	11.8	80	800	880
1 ft from yoke	~0.1	≈80	800	880

In target area, 4 in. Pb shielding → 20 mR/h inside shielded cart,
6 in. Pb shielding → 2.5 mR/h inside shielded cart.

FIGURE CAPTIONS

Fig. 1. 200 BeV Accelerator Facility.

Fig. 2. Layout of experimental areas.

Fig. 3. Shielding required for strongly interacting particles (SIP) and muons.

Fig. 4. EPB target stations J-BR and J-BL.

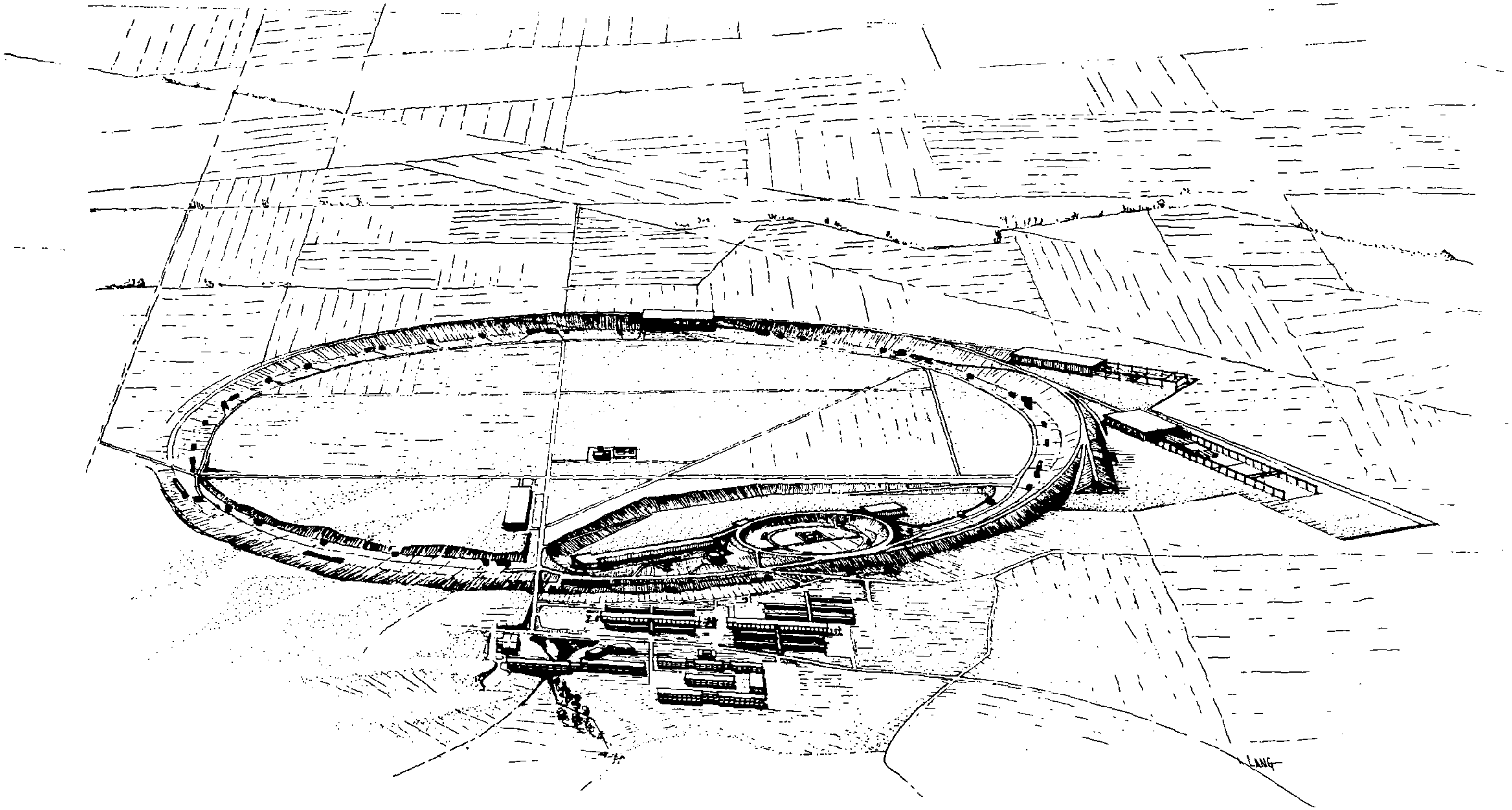

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Fig. 1.

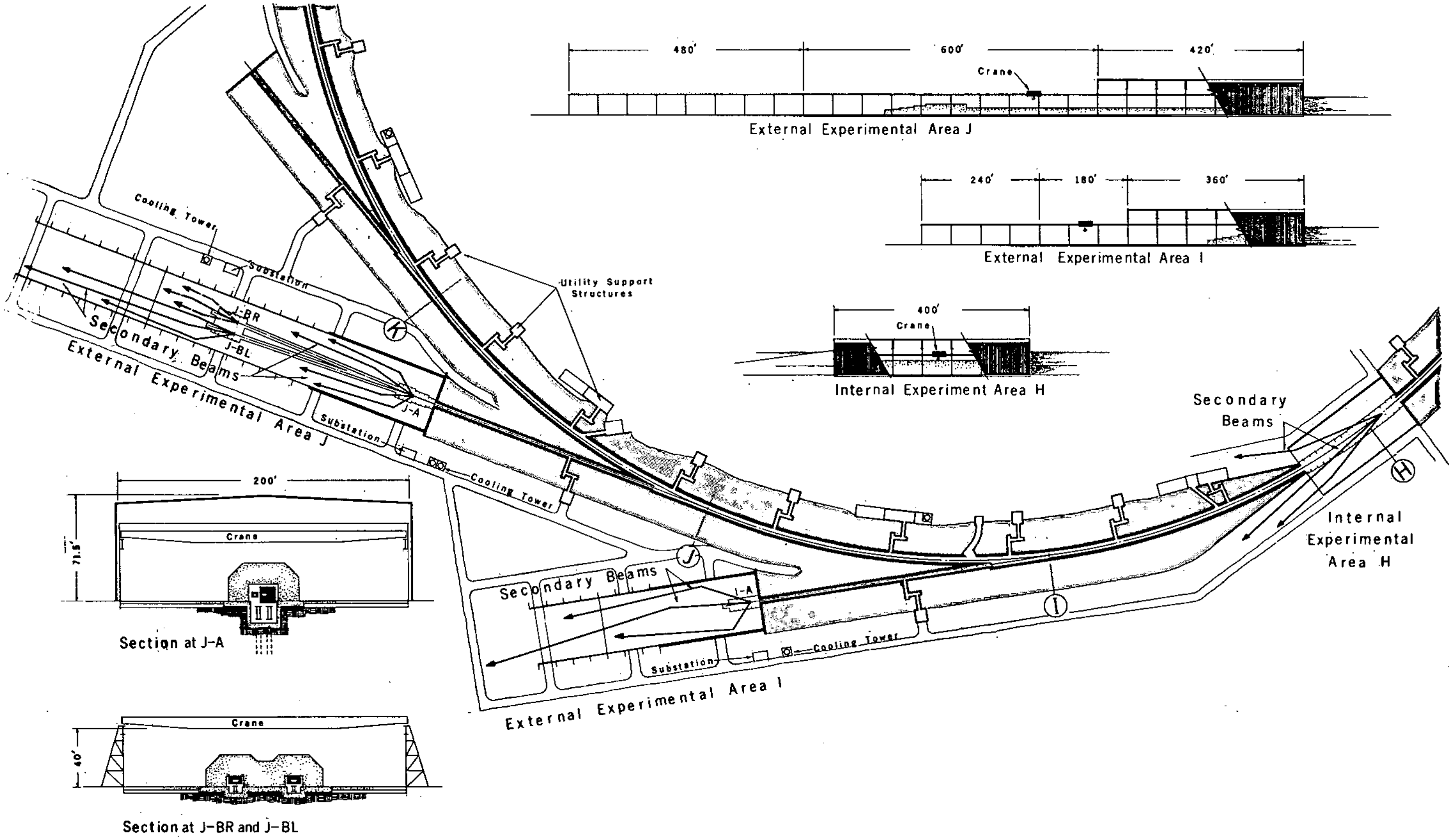
480'
600'
420'
Crane
External Experimental Area J
240'
180'
360'
External Experimental Area I
400'
Crane
Internal Experiment Area H
Utility Support Structures
Cooling Tower
Substation
J-BR
J-BL
J-A
Secondary Beams
External Experimental Area J
Substation
Cooling Tower
K
J
I
H
Secondary Beams
I-A
Substation
Cooling Tower
External Experimental Area I
Secondary Beams
Internal Experimental Area H
200'
71.5'
Crane
Section at J-A
40'
Crane
Section at J-BR and J-BL
MUB-6414

Fig. 2.

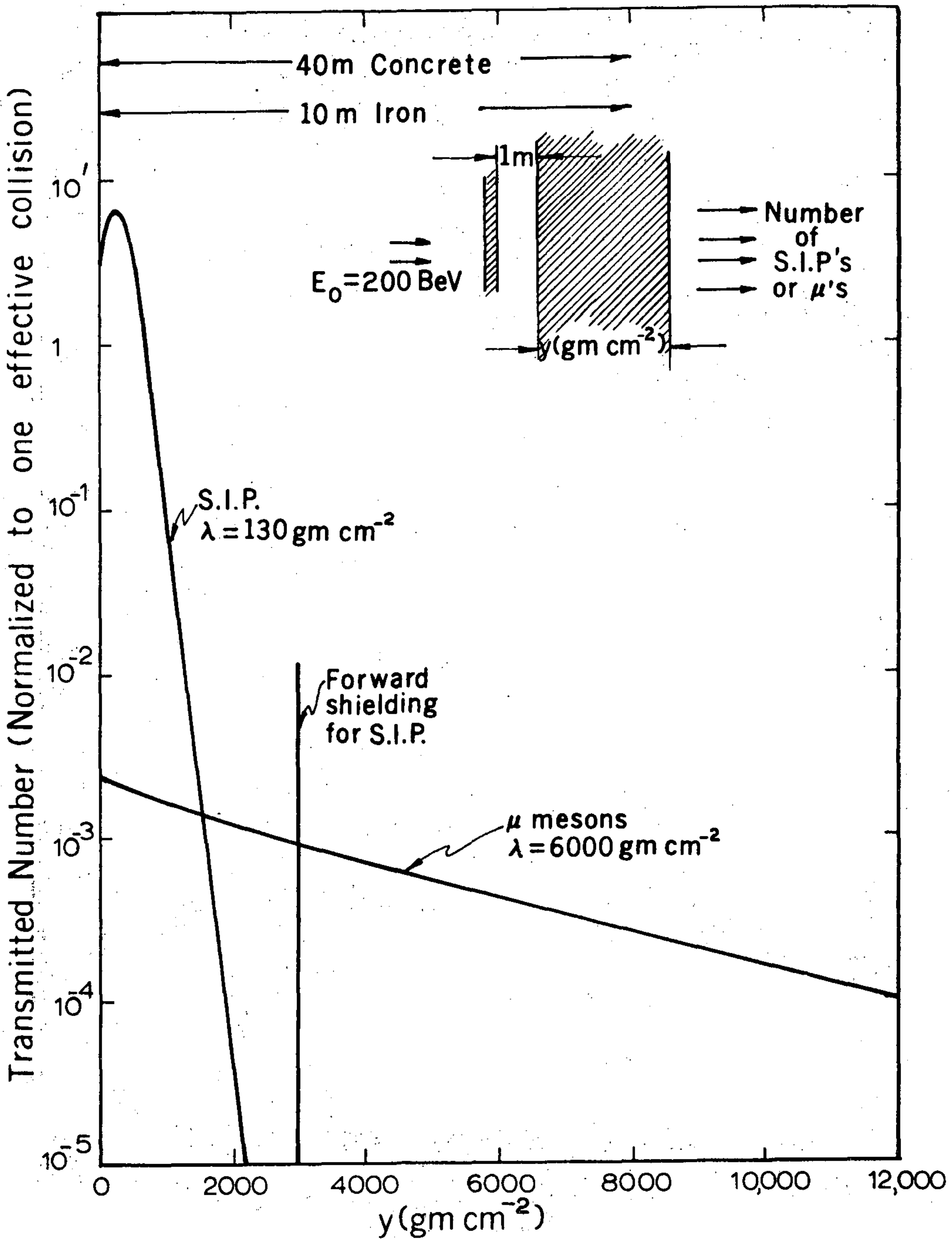

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Fig. 3.

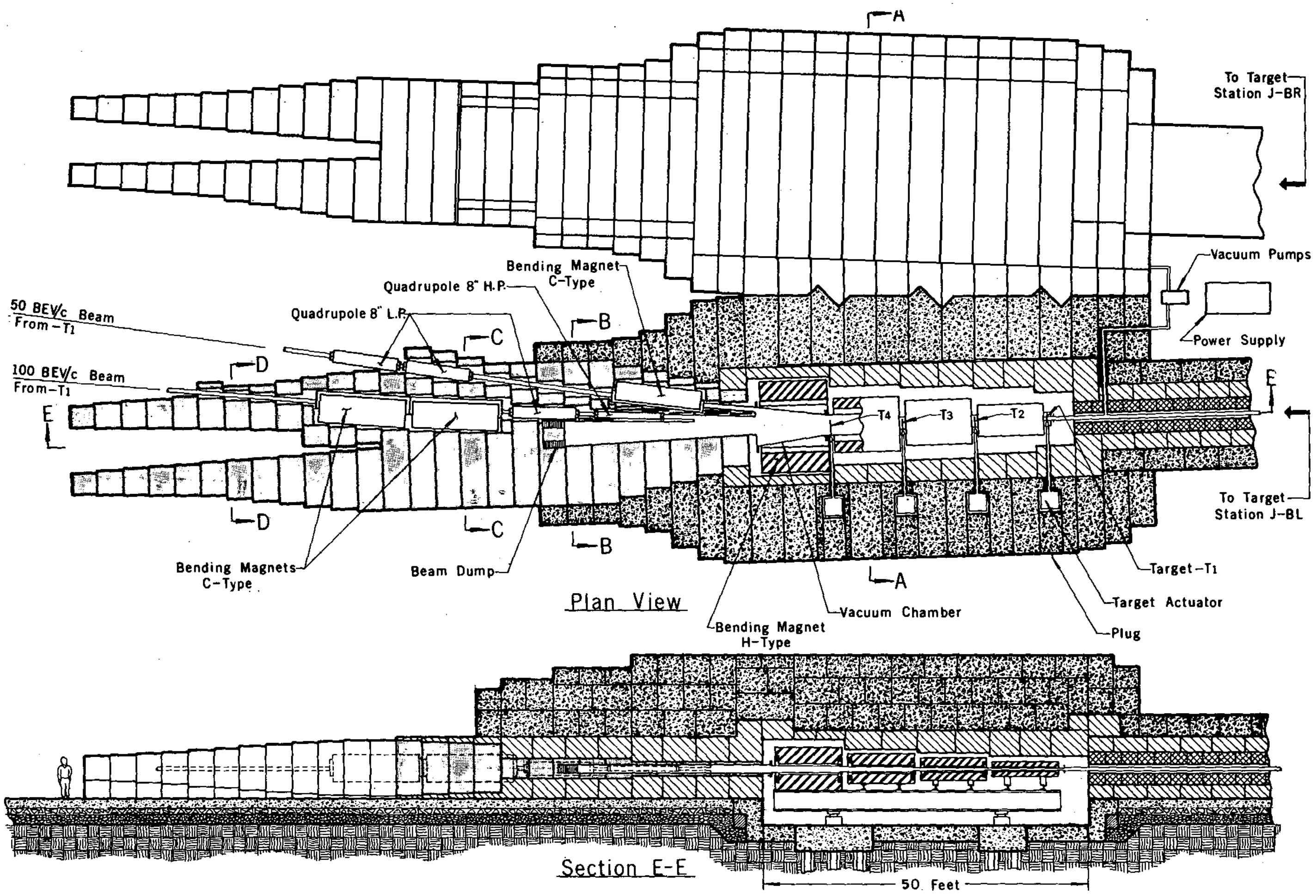

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Fig. 4.