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SHIELDING REPORT

REPORT OF THE AGS EXPERIMENTAL AREA

SHIELDING UPGRADE COMMITTEE

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INTRODUCTION

The proton intensity delivered to the AGS experimental areas is expected to increase fourfold when the full potential of the Booster is realized. It is therefore necessary to anticipate the modifications to the shielding and radiation monitoring that will be required in order to insure safe operation within the appropriate guidelines for radiation exposure.

This report examines the consequences of site boundary requirements and soil and air activation as well as the protection of radiation workers, i.e. AGS personnel and experimenters, from unnecessary radiation exposure in the experimental areas. Where possible, Health Physics surveys and fault studies carried out in the Spring of 1990 have been used to estimate levels in and around the experimental areas with 5 x 10^{13} protons per pulse or 75% of the total anticipated intensity delivered to each of the target stations under "normal" as well as fault conditions. Where fault studies were not possible due to construction, the new beams and facilities were designed for the higher intensities that will be avail-able and radiation patterns were calculated. Weak spots were identified and improvements recommended. Capital and manpower estimates were developed for the upgrades.

I. IMPLICATIONS OF SITE AND SITE BOUNDARY REQUIREMENTS.

This section describes the design goals for the on- and off-site dose equivalent from external radiation from protons extracted to the AGS Experimental Areas. Simple analytical functions [I-1,2,3] have been used to estimate on-and off-site dose equivalent. Working backwards from the design goals for annual dose, the thickness of shield needed to meet those goals was determined. The following is a description of the design goals, the methods used in obtaining them and a summary.

1) The shield shall limit the personnel dose equivalent rate at any continuously occupied location to as low as reasonably achievable (ALARA) but in no case shall the design produce greater than 0.5 mrem in 1 hour or 20 mrem in 1 week. Dose equivalent rates where occupancy is not continuous shall be ALARA but in no case shall the design produce greater than 1 rem in 1 year for whole body radiation, or 3 rem in 1 year for the lens of the eye, or 10 rem in one year for any organ or tissue.

2) The shield shall act as a proton beam stop to absorb the proton beam as well as secondary particles upon the occurrence of a fault. During this fault condition the maximum accumulated dose equivalent to

any area where access is not controlled, for example the roadway opposite C line, shall be less than 20 mrem.

3) The shield shall limit the annual site-boundary dose eqivalent to 5 mrem.

4) The shield shall limit the annual on-site dose equivalent to inadvertently exposed people to 25 mrem per person.

Design goal 1 is from DOE Order 5480.11. Design goal 2 is from the Argonne Pulsed Neutron Source and Proton Beam Line Shielding report by Marcel Barbier. Design goals 3 and 4 are BNL standards recommended by the Laboratory Safety Committee.[I-4]

Step One *Dose Equivalent From Neutrons Emitted In An Upwardly Direction*

The dose equivalent from skyshine due to neutrons emitted from the surface of an overlying beam line shield is given by Stevenson.[I-1] Neutrons emerge from the top of the shield and contribute to dose equivalent on the ground several hundred to several thousand meters away through interactions in the air column above the shield. The analytical function which describes this is from Reference 1 and is:

$$H(r) = 3 \times 10^{-13} e^{-(k\ r)}/r^2$$

where H is the dose equivalent in rem per neutron emitted in an upward fashion at distance r from the source, k is the volume macroscopic dose-reduction cross section for skyshine radiation for neutron interactions in air, and r is distance from the source in meters. As deduced from Reference 1, $k = 1.18 \times 10^{-3}\ m^{-1}$ for 28.5 GeV maximum energy neutrons. Based on Reference 1, the dose equivalent calculated for distances less than 400 meters is overestimated, and according to their graphs, probably by a factor of 2 for 28.5 GeV.

Step Two *Number of Upward Neutrons which Yield the Annual Dose Design Goal.*

A summary of the number of neutrons emitted from several locations which contribute 5 mrem and 25 mrem at areas of interest is given in Table I-1. The closest non-AGS uncontrolled location with full-time occupancy is the old Brookhaven Graphite Research Reactor (BGRR) complex. The closest uncontrolled AGS facility is Building 911. Occupancy at the BGRR complex and Building 911 is assumed to be 40 hours out of 168 hours per week or 25% of a running period.

Table I-1

Number of Neutrons Emitted from the Top of D, A, B or C Lines Which Produce 5 mrem at the Site Boundary and 25 mrem at Other Uncontrolled and Fully Occupied Locations

Target (design goal)	D Line	A Line	B Line	C Line
	(distance from the source to the target, m)			
Site Boundary (5 mrem)	1.7×10^{17} (1400)	1.7×10^{17} (1400)	1.7×10^{17} (1400)	1.7×10^{17} (1400)
BGRR Complex (25 mrem)	4.4×10^{16} (300)	6.0×10^{16} (750)	8.4×10^{16} (400)	1.2×10^{17} (450)
Building 911 (25 mrem)	8.8×10^{15} (150)	1.3×10^{16} (200)	2.8×10^{16} (250)	4.4×10^{16} (300)
Building 923[a] (25 mrem)	2.8×10^{16} (250)	1.3×10^{16} (200)	8.8×10^{15} (150)	3.7×10^{15} (100)

[a] Currently Bldg. 923 is a controlled area.

It appears that on-site facilities may be of greater significance than the site boundary. This depends on assumptions regarding local shielding, building classification with regard to radiation safety, and energy of neutrons. Building 923 is a controlled area which contains radioactive materials. For future running conditions, Building 923 should be labelled as requiring a film badge for entry. The nearest uncontrolled building is Building 911 which is closest to the D-line. Assuming that the neutron flux at Building 911 is equivalent to the fast flux from a PoBe source (> 0.5 MeV), 0.5 feet of concrete will attenuate the neutrons by a factor of 20. This factor of 20 due to 0.5 feet of local shielding raises the number of neutrons causing 25 mrem to 1.7×10^{17}. This is the same as the site boundary goal. Therefore, it is reasonable to assume that 1.7×10^{17} neutrons is the limiting value for upwardly mobile leakage neutrons for the AGS Experimental Areas.

Step Three *Total Area-Dose Equivalent Goal (rem-cm^2) for the Experimental Areas*

ICRP Publication 21[I-5] lists the dose equivalent per unit neutron fluence for 1/E spectra versus maximum neutron energy. If the analytical function by Stevenson is to be used to estimate dose equivalent from skyshine, the maximum neutron energy should be estimated from the maximum proton energy of the accelerator.

For 28.5 GeV, the conversion factor deduced from ICRP 21 is 2 x 10^7 neutron/cm^2 per rem. In a recent report, Stevenson indicates that a 1/E spectrum applies to dry concrete, but he also indicates that there are fewer low-energy neutrons from earth shields since earth contains water.[I-6] On the other hand, Stevenson tabulates measurements which indicate that 2 x 10^7 neutrons/cm^2 per rem is appropriate for a neutron spectrum from high-energy proton accelerators with thick earth shields. In that same report, he gives a value of 1.5 x 10^8 neutrons/cm^2 per rem for iron, and this value reflects the fact that iron is transparent to low-energy neutrons. These conversion factors and the design goal which in-corporates the value of 1.7 x 10^{17} neutrons from Step 1 are given in Table I-2.

Table I-2

Neutrons Per Unit Area Per Unit Dose Equivalent at the Surface of a Thick Shield for the Condition of 28.5 GeV Protons Interacting Behind the Lateral Shield
and
Total Annual Areal Dose Goal (rem-cm^2)

Shield Material	n/cm^2-rem	rem-cm^2(a)
Concrete	2×10^7	8.5×10^9
Earth	2×10^7	8.5×10^9
Iron	1.5×10^8	1.1×10^9

(a) Design goals 3 and 4 are met if no more than 8.5 x 10^9 rem-cm^2 (2.1 x 10^5 mrem-acres) are allowed during the annual proton running period and if concrete or earth are used at the outer parts of the shield wall.

Step Four *Dose Rate at the Surface of the Outer Shield Wall Per Proton Per Second.*

There are simple analytical relationships reported by Tesch for relating the surface dose equivalent to proton loss behind shielding,[7] and these can be used to interpret shielding limitations imposed by the design goals. For these calculations, the distance from the target to the inner surface of the overlying shield must be known, and 3.5 feet was assumed. In performing shield calculations, the overlying shield should encompass neutrons emitted upwardly into a vertical angle of ±45°. The mean chord length of magnets in the vertical angle of ±45° is assumed to be 1.4 feet. Table I-3, shows the attenuation offered by 4 different types of shield: 1) an overlying shield of concrete plus 1.4 feet of iron, 2) iron plus 2 feet of concrete at the outer surface, 3) concrete and 4) heavy concrete.

Table I-3

Dose Equivalent Rate at the Surface of a Lateral Shield from 28.5 GeV Protons for Different Slabs of Overlying Materials

Total(a) Thickness of Shield feet	Concrete Plus 1.4 feet of Iron	Iron Plus 2 feet Concrete	Concrete	Heavy Concrete
		mrem/h per p/s		
10	9.5×10^{-10}	7.1×10^{-14}	6.7×10^{-9}	9.4×10^{-10}
15	2.4×10^{-11}	1.5×10^{-18}	1.8×10^{-10}	9.3×10^{-12}
20	7.5×10^{-13}	3.5×10^{-23}	5.6×10^{-12}	1.1×10^{-13}
25	2.6×10^{-14}	9.2×10^{-28}	1.9×10^{-13}	1.4×10^{-15}
30	9.4×10^{-16}	2.6×10^{-32}	6.8×10^{-15}	1.9×10^{-17}

(a) The total is the sum of iron plus concrete where appropriate.

Step Five *Shield Thickness Versus Areal Dose and Surface Dose Rate.*

Three assumptions are needed to estimate areal dose and shield surface dose rate:

1) a running period of 20 weeks at 5 x 10^{13} protons per pulse and 1 pulse every 2.5 seconds; that is, 2.4 x 10^{20} total protons at the average rate of 2.0 x 10^{13} p/s,

2) each beam line is designed to take 2.4 x 10^{20} protons per annual running period, and

3) upward neutrons from a point source of protons emerge from a shield surface area of 2000 ft^2 (1.9 x 10^6 cm^2). The neutron leakage of the AGS Ring was measured in the J super-period using the J19 flip target as a point source. The target was about 23 feet below the shield top. The effective area of the neutron emission was estimated using plots of radiation versus position both transversely and longitudinally outside the shield top, giving about 2000 ft^2, see Reference *I-8*.

Based on these assumptions, the following dose rates at the surface of a concrete shield and the annual areal doses are estimated and listed in Table I-4.

Table I-4
Shield Thickness Versus Areal Dose and Surface Dose Rate for
2.4 x 10^{20} Protons in an AGS Beam Line

# MFPs(a) (feet of concrete)	Surface Dose Rate, mrem/h	Annual(b) Areal Dose, rem-cm2
6 (10)	1.3×10^5	8.3×10^{11}
9 (15)	3.6×10^3	2.3×10^{10}
12 (20)	1.1×10^2	7.0×10^8
15 (25)	3.8×10^0	2.4×10^7
18 (30)	1.4×10^{-1}	8.9×10^5

(a) MFP is the dose reduction mean free path. In the lateral direction for 28.5 GeV protons, 1 MFP of earth (1.8 g/cm^3) is 117 g/cm^2. For pure iron it is 200 g/cm^2, for iron which is capped with 1 MFP of concrete it is 117 g/cm^2, for concrete (2.3 g/cm^3) it is 117 g/cm^2 and for heavy concrete (3.5 g/cm^3) it is 134 g/cm^2. If iron is used, the final MFP should be concrete or earth since iron is transparent to low-energy neutrons.

(b) The total annual areal dose goal is 8.5 x 10^9 rem-cm^2, see Step 3. This translates into 1.7 x 10^9 rem-cm^2 per beam line including the appropriate portion of the switchyard.

Summary.

For future running conditions, Building 923 should be upgraded to require a film badge for entry.

In general, meeting the annual areal dose goal for a 20-week running cycle translates into the following:

1. Shield top dose rates should average less than 1400 mrem/hr for a 2000 ft^2 surface area.

2. For larger surface areas of loss, such as more than one target cave roof plus several loss points in transport lines, the product of average dose rate over 20 weeks and shield-top surface area should be less than or equal to 1400 mrem/h x 2000 ft^2.

From Table I-4, an annual 1% loss in transport through a 10-foot concrete (or 7.5-foot heavy concrete) shield in a single beam line results in an annual areal dose of 8.3 x 10^9 rem-cm^2, which is virtually the limit for annual areal dose goal for the AGS Experimental Areas. Additionally, full-fault dose rates at the 10 foot shield surface would be 130 rem/h. Thus, transport lines should be designed accordingly, allowing for consideration of several percent for transport losses and for the full fault, which should be no more than 20 mrem per full-fault event (see design goal 2). Typically, 15-foot concrete side walls (or 11 feet of heavy concrete) and 15-foot overlying shields (11-foot heavy concrete) are used in the transport lines. This allows 5% transport losses, and a chipmunk area-monitor response time of 20 seconds for a fault condition producing less than 20 mrem. However, for 15-foot thick concrete (11-foot heavy concrete) transport lines, the surface dose rates under the full fault condition could be 3.6 rem/h which makes the transport lines a potential "High Radiation Area." The transport lines would have to be monitored by chipmunk area monitors, and be surrounded by a locked fence. Fencing and monitoring for proton losses could be eliminated if 20-foot thick concrete (15-foot heavy concrete) transport lines were built.

Protons at the target areas are effectively shielded with a minimum of 20 feet (15-feet for heavy concrete) of lateral concrete. For 5 beams lines, this yields 35% of the leakage neutrons corresponding to the design goal for the annual areal dose. The routine surface dose rates are 110 mrem/h, however. Access to the area near the targets would have to be controlled as routine "High Radiation Areas." Additionally, direct shine from the target area shields becomes significant for 20-foot lateral shields. A 2000 ft^2 area source of 110 mrem/h would produce significant dose rates 50 to 100 feet away. The direct radiation through the shield would also be significant. The use of 25-foot lateral (19-feet for heavy concrete) shields around targets would help meet design goal 1, and virtually eliminate the target areas as contributors to the annual areal dose goal.

References

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I-3 K. Tesch, "Comments on the Transverse Shielding of Proton Accelerators," Health Physics 44, pp. 79-82, 1983.

I-4 W. R. Casey to M. Brooks, Chairman, Laboratory Radiation Safety Committee, "Radiation Exposure Criteria," BNL Memorandum, February 4, 1988.

I-5 International Commission on Radiological Protection, Data for Protection Against Ionizing Radiation from External Sources:

Supplement to ICRP Publication 15, ICRP Publication 21, Pergamon Press, Oxford, 1973.

I-6 G. R. Stevenson, Dose Equivalent Per Star in Hadron Cascade Calculations, Divisional Report, European Organization For Nuclear Research, TIS-RP/173, May 26, 1986.

I-7 Ibid, References 2 and 3.

I-8 K. Brown, J. Glenn, S. Musolino, A. Stevens, and R. Thern, "AGS Shield Tests," AGS Studies Report Number 245, Brookhaven National Laboratory, Upton, NY 11973, November 4, 1988.

II. STATUS OF THE EXPERIMENTAL AREAS.

II-1 THE SLOWLY EXTRACTED BEAM SWITCHYARD.

If the results of the Spring 1990 fault studies(II-1) are extrapolated to intensities anticipated during Booster operations, the present Switchyard shielding is adequate in most areas. Side walls are 10-12 feet of heavy concrete and the roof is 8 to 10 feet equivalent. A fault condition in which the entire beam was lost would lead to 5 to 30 rem/hour on the roof and 1-3 rem/hour outside the walls which would make them High Radiation Areas. A single CHIPMUNK type interlocking the beam would provide adequate protection for this fault. A typical point loss of 2%, e.g. putting a flag in the beam, would result in levels of .1 to 5 rem/hour on the roof and 10-30 mrem/hour outside the walls which would also be acceptable if the condition did not exist for more than a small fraction of hour.

The most serious loss area in the Switchyard is in the upstream end where the thick Lambertson magnets AD2, AD3, DD4 and DD5 are located with the small aperture dipoles CD2 and CD3. The next worst spot is near the thick Lambertson magnet, BD4. These magnets should be replaced with Lambertson magnets having thinner septa and dipoles of larger aperture should replace CD2 and CD3. This would result in a factor of two reduction in beam loss.

The most pervasive problems in the Switchyard are the breaches in the shielding due to the nine trench penetrations under the shield walls and the five structural columns that penetrate the roof shielding. If these holes can be filled to reduce the surface levels to ten times adjacent levels, then additional area monitor interlocks or fences would limit the effect of major faults while allowing typical (flag) losses. Since the area of these holes represents a small fraction of the total shield area, their contribution to skyshine is expected to be small.

II-2 THE "A" TARGET STATION AND THE A1, A2 and A3 SECONDARY BEAM LINES.

Shielding for "A" Target Primary Cave.

The "SEB Fault Studies Summary" as amended May 3, 1990(II-1) provides the information for determining the radiation levels in the areas surrounding the "A" target primary beam cave. In Fig. II-2-1 the levels extrapolated to 5 x 10^{13} on the "A" target are given for normal operations. There would exist a general level of approximately 50 mrem/hr along the western wall. This presumably could be handled by making most of this area off limits during high intensity operations. The beam dump of the "A" primary beam had a level on the shielding roof of 450 to 650 mrem/hr. A combination of additional shielding and a policy of making the roof off limits should keep this area within the guidelines.

The one fault studied was steering the beam into the A1C2 collimator. The area levels were unchanged or lowered except that the level on the roof over the collimator went from < 100 mrem to 700 mrem. Colliding the primary beam with other elements in the beam line would result in the same or lower levels on the roof. Alarming devices would be required at 5 x 10^{13} incident to keep the levels on the roof within acceptable limits.

A3 Beam Line.

There is no further projected use of the A3 line as primary beam transport. The A3 target cave was designed for 1 to 2 x 10^{12}, and would need a major rebuild for operation above this level. No fault studies were carried out for the A3 line as primary proton transport during the recent survey. As a secondary beam line for testing apparatus, the beam line will be enclosed with shield walls, and there will be intensity limiting devices for maintaining levels within their proper limits. Fault studies will be carried out as soon as construction is complete and beam is available in the FY1991 SEB cycle.

A2 Test Beam.

The A2 test beam operates at a relatively low intensity within a fenced area. NMC paddles are employed to maintain the intensity level below prescribed limits. Unless these limits are raised, no additional shielding is required.

A1 Unseparated Beam.

This long beam line transports secondary particles to the Multiparticle Spectrometer (MPS). NMC paddles are used to limit the overall beam intensity and area monitors are used to check that there are not excessive losses along the beam transport. At present the security system prevents the transport of positive beam in the "A" line.

The beam is enclosed in pipe along its entire length and there exist local fences as well. The MPS cannot take fluxes above the present level of 2.0 x 10^6. Provided that the beam stays within this limit, no additional shielding is necessary.

II-3 THE "B" TARGET STATION AND THE B1, B2 AND B5 LINES

"B" Line Proton Intensity Considerations.

The present "B" target station feeds one secondary beam B2, the Medium Energy Separated Beam (MESB) to the MPS. Downstream of the "B" target, two primary beam branches deliver either primary protons to the "B′" target in the B5 line or primary relativistic ions to Experiment 859 in the B1 line. Generally, the "B" target is the lower intensity area, whereas the "B′" target has been designed to run at 1.0 x 10^{13} protons per pulse and the ion beam, B1, is of low intensity with few interactions in the experimental target and is therefore not relevant to this study. The "B′" target provides a neutral beam for Experiment E791 which is now complete. We anticipate that a new proposal for higher intensity will necessitate some changes in the beam, probably displacing the "B′" target upstream.

"B" Target Station Limit.

Figure II-3-1 shows the "B" target area shielding configuration, and radiation pattern scaled to 5 x 10^{13} protons/pulse from normal running with 3.5 x 10^{12} ppp on "B". The measurements indicate an acceptable maximum of 4 x 10^{12} ppp on "B" with the present shielding configuration.

The front end of B2, including the first electrostatic separator is presently unshielded. The two magnetic septa B2D1 and B2D2 are already approaching their anticipated life expectancy. Were the MESB to be used at higher intensities, they would have to be replaced by new septa with radiation resistant coils. Even under present running conditions 60 mrem/hour at the "B" gate gives a 16 hour maximum occupancy with beam on. The level of 9 mrem/hour in the corridor implies a limit of 100 hours. Levels in the MPS counting area were 0.4 mrem/hour and 1 mrem/hour on the 2nd floor of the E791 counting house.

Additional shielding is needed as indicated and in Table II-3-2. It would also be necessary to create an inner target cave as shown to protect downstream magnets and to replace the first septa B2D1 and B2D2 and first quadrupole B2Q1 with radiation resistant magnets. The forward shielding in B2 should also be examined.

Table II-3-2
Shielding for B-target upgrade to $5x10^{13}$ ppp

Area	Requirement
"B" Gate	The labyrinth should face upstream, with at least 3 feet equivalent light concrete added.
E791 Counting House	3 feet light concrete equivalent is needed between the B2(MESB) mass slit and the E791 counting house.
Roof	Additional shielding would be required with a new area configuration.
"B" Target Cave	Radiation-hard magnets would be required, and an inner cave designed for a high intensity target station.

"B′" Target Limits.

The "B′" target station is a custom arrangement for a single experiment, E791, that required high intensity, up to 10^{13} per pulse but typically at 5×10^{12}, and a short neutral beam. Although the present experiment has been completed, a follow-on experiment may be proposed which would have similar requirements.

At 1.0×10^{13} protons per pulse, the epoxy fiberglass insulation of the coils of the first sweeping magnet B5P4 would only survive for about 1000 hours. Changing it to a radiation-hard design would be required. Then, at 5×10^{13} per spill, beam could be used with additional shielding as indicated in Table II-3-2. However, a complete redesign of the target area would be needed for removal and maintenance of the beam elements.

Table II-3-2

Shielding "B′" for 5×10^{13} Protons per Pulse

Area	Requirement
E791 Counting House	Four feet light concrete equivalent added to the south wall
Roof	Four feet additional shielding required
"B′" Target Cave	High intensity target station re-required, radiation-hard sweeping magnet (B5P4)

Limiting Apertures.

The quadrupole B5Q3 is highly activated and beam losses in the area as well as beam calculations indicate that the three inch aperture is inadequate. The rest of the "B" line should be checked for residual activation.

Faults and Corrections for 5×10^{13} protons per spill in the "B" Line.

The recent fault studies used, typically 1×10^{12} per pulse. Figure II-3-1 shows levels scaled to 5×10^{13} targeted at "B" and "B′" respectively. The scaling for the "B" target is meaningless inasmuch as neither the target station-secondary beam configuration or the existing experimental facilities in this area are capable of or have any need for intensities beyond 3×10^{12} protons per pulse. In the event that future proposals would require significantly higher intensity, the area would be rebuilt accordingly. A new proposal for an upgrade of E791 is anticipated which could go to proton intensities in excess of 1.0×10^{13} on the "B′" target. Four feet additional heavy concrete shielding would be required over the target to maintain rooftop levels and levels in the E791 counting house at their present values.

II-4 THE "C′ AND "C′" TARGET STATIONS AND THE C1, C4, C3, C6 AND C8 BEAMS.

Shielding Under Normal Conditions.

Figure II-3-1 shows the radiation levels which can be expected around the "C" line assuming 5 x 10^{13} protons/spill on the "C" target at 24 GeV/c and a 3.2 second machine cycle. Most of the levels are scaled up from Health Physics surveys and dedicated fault studies undertaken in 1990.(*II-1*) The values given include estimates based on an assumed beam loss of 3% at CQ12, which is a 3Q36 quadrupole producing a typical loss in the vicinity of loss monitor CL47L, and the roof shielding thickness (Fig. II-3-1). A similar calculation gives 4300 mrem/hour for 5 x 10^{13} protons interacting at the "C" target station compared to 1700 mrem/hour deduced from Health Physics surveys. A level of 2300 mrem/hour on the roof at column H20, immediately downstrean of CQ12 and upstream of the "C" target, is an estimate based on fault studies in which a 63% loss was created near CL47L.

The levels in the road near the "C" target upstream gate would exceed the 5 mrem/hour limit for a Controlled Area. Also, 2300 mrem/hour on the roof would exceed the 100 mrem/hour limit for a Radiation Area. Additional shielding is clearly required here although column penetrations in the roof may contribute the bulk of the leakage.

At present two points in EEBA are above the 100 mrem/hour limit for a Radiation Area levels: one at the trench at N16600 and the other just outside the C6/C8 downstream separator cave gate. There is some uncertainty in scaling this latter point. In two HP surveys where the C3 target intensity was 1.3 x 10^{12} and 1.0 x 10^{10}, the surveys show 45 mrem/hour and 30 mrem/hour respectively, illustrating the difficulty of using simple scaling of intensities in complex areas containing multiple sources.

The Lambertson magnets C1D1 and C3D1, which allow simultaneous operation of C1 in either polarity and the delivery of protons to the "C′" target for experiments in the LESBII (C6/C8), are highly activated indicating large losses. Their contribution to rooftop radiation can be seen in Figure II-3-1 where levels rise to 170 mrem/hour over C3D1 which has no steel over its upper aperture.

Shielding Under Fault Conditions.

The numbers shown in parentheses in Figure II-3-1 indicate the levels which could be produced by faults of 5 x 10^{13} protons per spill at 24 GeV/c and a 3.2 second machine cycle. The data are scaled from fault studies.(II-1) The upstream data are from a fault near CQ12, and the down-stream data from a fault on C3Q8 and C3Q9. Note that this fault is some distance downstream of the trench at N16600, which has a potential for 3.9 rem/hour. In a fault study, in which the beam was dumped much nearer to the trench upstream of C3D2, the level was only one third as high.

II-5 THE "D" TARGET STATION AND THE D1, D3 AND D6 BEAMS

The "D" Line did not run during the latter part of the FY1990 SEB period since the downstream section was under construction for the installation of the 2 GeV/c Separated Beam. It therefore was not subjected to the intensive fault studies that were carried out in the rest of the East Experimental Area. Fault studies will be carried out as soon as the AGS proton program resumes in FY1991. The effectiveness of shield walls and penetrations can be estimated but the strengths of possible sources are more assumption dependent. The fault studies will establish the source strengths.

It is anticipated that in the short term it will be necessary to install radiation monitors at the weak points in the shielding, e.g. the five trenches that run underneath the "D" line and the west shield wall. Under normal operation the existing shielding should be adequate but fault conditions involving intensities of 5 x 10^{13} protons/pulse are likely to cause excessive levels at the weak points. With the information obtained from the studies program, corrective shielding can installed. The anticipated program in the "D" line requires a maximum intensity of 2 x 10^{13} protons/pulse.

The downstream section of the beam beyond the polarized proton target (N13500) would probably require the following conditions be satisfied to meet a goal of 100 mrem/hour maximum for a full fault in the unrestricted sidewall areas.

1) The magnets D1D10 and D1D11 that are part of the forward arm of the polarized proton spectrometer must be in place or be replaced by an appropriate amount of steel in the event that they are removed.

2) The two trenches that run under the east wall at N13800 and N14250 should be packed to meet the requirement of less than

100 mrem/hour for a full fault. The trench at N14250 is covered with concrete inside the "D" cave.

3) The beam dump was conservatively designed for 10^{13} protons/pulse and is expected to be adequate for several times that. The fault studies should verify the design.

4) The two trenches under the west wall at N13800 and N14250 will require modification.

5) Access to the top of the shielding should be restricted.

The upstream region is more difficult to modify but it also involves a lower occupancy. The areas outside both side walls have to be protected against fault conditions by active radiation detectors and interlock devices or be restricted areas. The area outside the east wall of the "D" line can have elevated levels from fault conditions in the "A" and "D" lines. It would best remain a restricted area. The west side should be a restricted area and be protected by active detectors and interlocks as well.

The "D" line shielding is penetrated by nine trenches, three labyrinths, two spectrometer ports for polarized protons two secondary beam lines, an instrumentation port and helium and vacuum lines for the polarized proton apparatus. These are listed in Table II-5-1.

TABLE II-5-1

"D" LINE SHIELDING PENETRATIONS

LOCATION	AREA OF CONCERN FOR RADIATION
Trench at N11600	Building Column A6 on Shield Top
Trench at N11900	Building Column A7 on Shield Top
Trench at N12300	Building Column A9 on Shield Top
LOCATION	AREA OF CONCERN FOR RADIATION
Trench at N12500	Building Column A10 on Shield Top
Trench at N12700	"D" Line east wall
Trench at N13100	"D" Line east and west walls

TABLE II-5.1 (continued)

Trench at N13400	"D" Line east and west walls
Trench at N13800	"D" Line east and west walls
Trench at N14250	"D" line east and west walls
"D" South Gate Labyrinth	"D" Line west wall
"D" North Gate Labyrinth	"D" Line west wall
Switchyard Labyrinth	"D" Cave
E794 spectrometer recoil arm port	"D" Line west wall
D2 Beam Line	"D" Line west wall
D6 Beam Line	"D" Line west wall
"D" Target Instrumentation port	"D" Line east wall
Polarimeter target vent	"D" Line shield top
E794 polarized target port	"D" Line west wall

The following neutron attenuation in the labyrinths have been estimated using the formulas of Tesch.[II-2]

"D" South Gate labyrinth	3.6×10^{-7}
"D" North Gate labyrinth	1.6×10^{-5}
Switchyard to "D" Line labyrinth	3.0×10^{-5}

The attenuation of neutron leakage in trenches can be most effectively reduced by installing vertical labyrinths (doglegs) which according to the Tesch formula yields a factor of six per dogleg.

Weak spots in the shielding exist on the east wall at N12700 and above AQ6 which is .5 foot thinner than the accepted eight feet of heavy concrete. Sections of the catwalk are exposed to thin sections of "D" line shielding. Building column penetrations can be improved by pouring concrete into forms that transform the "I" sections into square sections which are more readily shielded.

The recoil arm ports of the E794 spectrometer should be shielded when running high intensity protons in the "D" Line. E794 operates with a maximum of 3.0×10^{11} protons/pulse in which case the shielding could be removed if it was not compatible with the experiment. The beam pipe aperture from DD223 to DQ10 is being increased from 3 to 5 inches which should greatly reduce losses due to scraping in this area.

II-6 THE U AND V LINES.

The U Line, as it now exists, is shielded largely by a sand covering, in contrast to the SEB lines which are covered mostly by heavy (ilmenite loaded) concrete blocks. Entrance openings are shielded by small concrete labyrinths. Some weak spots near the upstream end are shielded with steel "anchor buoys". The "U" target region is surrounded by a concrete (light and heavy) blockhouse, cut into the sand shield and concrete tunnel. Some steel plates and billets have been incorporated in the top and East side here to improve the attenuation of leakage radiation.

Dose rates outside the shielding have been calculated using a hybrid expression given by H. Foelsche.[II-3]

$$dR/dt = \frac{6.2 \times 10^{-5}}{r} \text{ (mr-ft/hour)} \times 10^{(-s/a)}$$

where dR/dt = dose rate per (lost proton/sec), s = shield thickness, a = attenuation length, and r = distance (feet) from the interacting beam. The 1/r dependence is appropriate for a line source and was used since a beam on a thick target actually dissipates energy over a fairly long distance, 40-50 feet downstream. The constant was derived from measurements with such a target inside a sand shield, and the results compared with other measurements at the "C" target.

The attached diagrams of the U and V lines have been marked to indicate the dose rates expected at the outer shield surface for full beam (5.0×10^{13} protons/sec) "point" losses at the locations indicated. The rates are in mrem/hour or rem/hour as shown. Values written over the beam lines are for the shield top. Others are the rates calculated for grade level at the location indicated. The dose rates shown are, of course, for fairly localized or point losses. Normal beam scraping losses over a long section of beam pipe would be common here, reducing the dose rates shown by a factor of 50-100. However, fault conditions could lead to rates of 0.1 to 1.0 times the values shown, e.g., bad missteering or failure of the 8 degree bend.

There is a long section of "U/V" and "U"tunnel where rates of 500-750 rem/hour for full fault conditions are indicated in Figures II-6-1 and II-6-2. If normal losses are 3% in this area, the dose rate would be 15-23 rem/hour for loss at a single point. Using an estimate of 2000 square feet from Section I for the effective external area of irradiation for a point loss, an areal loss rate of (2.75-4.25) x 10^7 rem-cm^2/hour would result. Twenty weeks, or 3000 hours of operation per year, would lead to (9.5-14.0) x 10^{10} rem-cm^2 which is 11-16 times the design goal for the entire AGS. This is where there are only 10 feet of cover over the tunnel. An additional 6 feet of sand would be necessary to bring the total areal dose below the design limit.

The section up to the 8 degree bend must also be improved for the new "V" Target operation for E821, which will use the full beam. The remainder of the "U" Line should clearly be improved if a future neutrino experiment is run from the "U" target. This is also true of the "W" Line if full intensity protons are ever transported to the RHIC. Slightly higher levels are found over the "W" Line branch to the RHIC, where there is only a 10 foot cover and no concrete tunnel. Other trouble spots are at the substation near the railway entrance into the U Line (3-170 rem/hour) and in the rectifier house up on the berm between the U Line and the AGS (90-140 rem/hour). These areas require special study. High radiation levels are also possible outside the neutrino horn railway entry (5.8-19.0 rem/hour), and at the vehicle roadway gate leading to the berm top (7.8-14.5 rem/hour). These areas require the installation of at least 6 feet of heavy concrete.

At the planned "V" Target, the side radiation seems manageable (2.5-62.5 mrem/hour), and levels above the target will be satisfactory (7.5-97.5 mrem/hour) if about 9 feet of sand are added to the 9 feet of heavy concrete already envisioned there. Using the results of A.H. Sullivan,[II-1] at the end of the 40 foot Fe beam stop at the "V" Target, the estimated dose rate is about 2.25 rem/hour. This stop must be made thicker than planned by 10-13 feet, bringing the rate down to about 100 mrem/hour. The muon beam will have a diameter at half maximum intensity of about 5 feet compared to the stop width of 10 feet. The muon beam will be approximately Gaussian, falling off by a factor of 16 at the edge of the stop.

II-7 CAPITAL AND MANPOWER ESTIMATES FOR THE UPGRADE.

High radiation levels in the experimental areas under normal operation derive mainly from five sources: insufficient apertures in beam components, breaches in the shielding by trenches carrying power cables and water pipes, holes in the roof shielding around building and crane rail support columns, (I-beams), insufficient shielding, particularly over target stations and at labyrinths and high loss areas, and improp-perly stacked shielding. The cost of replacing magnets of insufficient aperture is approximately $50K per quadrupole and $100K for each dipole and $150K for each Lambertson magnet. Three quadrupoles, B5Q3, CQ11, and C3Q9, two dipoles CD2 and CD3 and seven Lambertson magnets AD2, AD3, DD4, DD5, BD4, C1D1 and C3D1 should be replaced at a cost of:

Magnet Subtotal	$1400K

The following generic estimates can be used to determine the cost including labor of upgrading the shielding in the East Experimental Area:

Remove existing cables, hoses and tray from an existing trench, install a three foot vertical concrete labyrinth and replace services.	$25K
Remove an existing shield roof, form and pour light concrete around a structural column and replace the roof.	$12K
Materials and labor to add 2 feet 3 inches of light concrete on top of an existing 24 foot wide roof.	$.75K/ft
Materials and labor to add 4 feet of light concrete to an existing 34 foot wide roof.	$1.85K/ft

The total cost of upgrading the trenches and columns would then be

27 trenches @ 25K per trench	$675K
12 columns @ $12K per column	$144K
Trench and Column Subtotal	$819K

Upgrading the roof shielding would cost:

"B" and "B′" target station roofs - 4 feet of light concrete	$259K
Shield E791 Counting House from B2 and B5 beams	$ 24K
"C" target station roof	$405K
"C" primary cave East Wall	$ 25K
Add 6 feet of sand to the "U" Line	$335K
Add 9 feet of sand to the "V" Line	$ 50K
Shielding Subtotal	$1098K

The costs for upgrading the primary beam labyrinths are:

"B" Labyrinth	$85K
"C" Labyrinth	$25K

Labyrinth Subtotal	$110K
Total	$3427K

Procurement of a magnet typically takes two years. Assuming the availability of a dedicated rigging crew, the shielding upgrade could be completed in five years.

References

II-1 D. Beavis, H. Brown, I-H. Chiang, A. Etkin, J. W. Glenn, S. Musolino, A. Pendzick, P. Pile, K. Reece, A. Stevens and K. Woodle "SEB Fault Studies Summary", April 28, 1990 amended May 3, 1990

II-2 K. Tesch, "The Attenuation of the Neutron Dose Equivalent in a Labyrinth Through an Accelerator Shield", Particle Accelerators 12, 169, (1982)

II-3 H. Foelsche "Side Shielding and Associated Radiation Security Systems for Primary Proton Lines and Caves", 10/11/77.

II-4 A. H. Sullivan, "A Method for Estimating Muon Production and Penetration Through a Shield", NIM A239, 197, (1985).

Figure Captions

Figure II-2.1 THE EAST EXPERIMENTAL BUILDING.

The estimated "A" line radiation levels for normal operation with 5 x 10^{13} protons/pulse are indicated. Estimates are not given for the "D" Line which has been under construction for the past year so that fault studies have not been possible. The new "D" target stations is designed to accept intensities in excess of 10^{13} protons/pulse. Fault studies will be carried out as soon as beam becomes available in this area in FY1991.

Figure II-3-1 THE EAST EXPERIMENTAL BUILDING ADDITION.

The estimated "B", "B′", "C" and "C′" line radiation levels are given for normal operation and in parentheses for full fault conditions scaled to 5 x 10^{13} protons/pulse from fault studies at lower intensities.

Figure II-6-1 THE UPSTREAM SECTION OF THE "U/V" LINE.

The calculated radiation levels are indicated for full fault conditions with 5 x 10^{13} protons/pulse. The "U" Line has not been run for several years and it has not been subjected to fault studies more recently.

Figure II-6-2 THE DOWNSTREAM SECTION OF THE "U" LINE.

The calculated radiation levels are indicated for full fault conditions with 5 x 10^{13} protons/pulse. The"V" Line is presently being designed to accept the full AGS intensity of 6 x 10^{13} protons/pulse with the AGS Booster in operation.

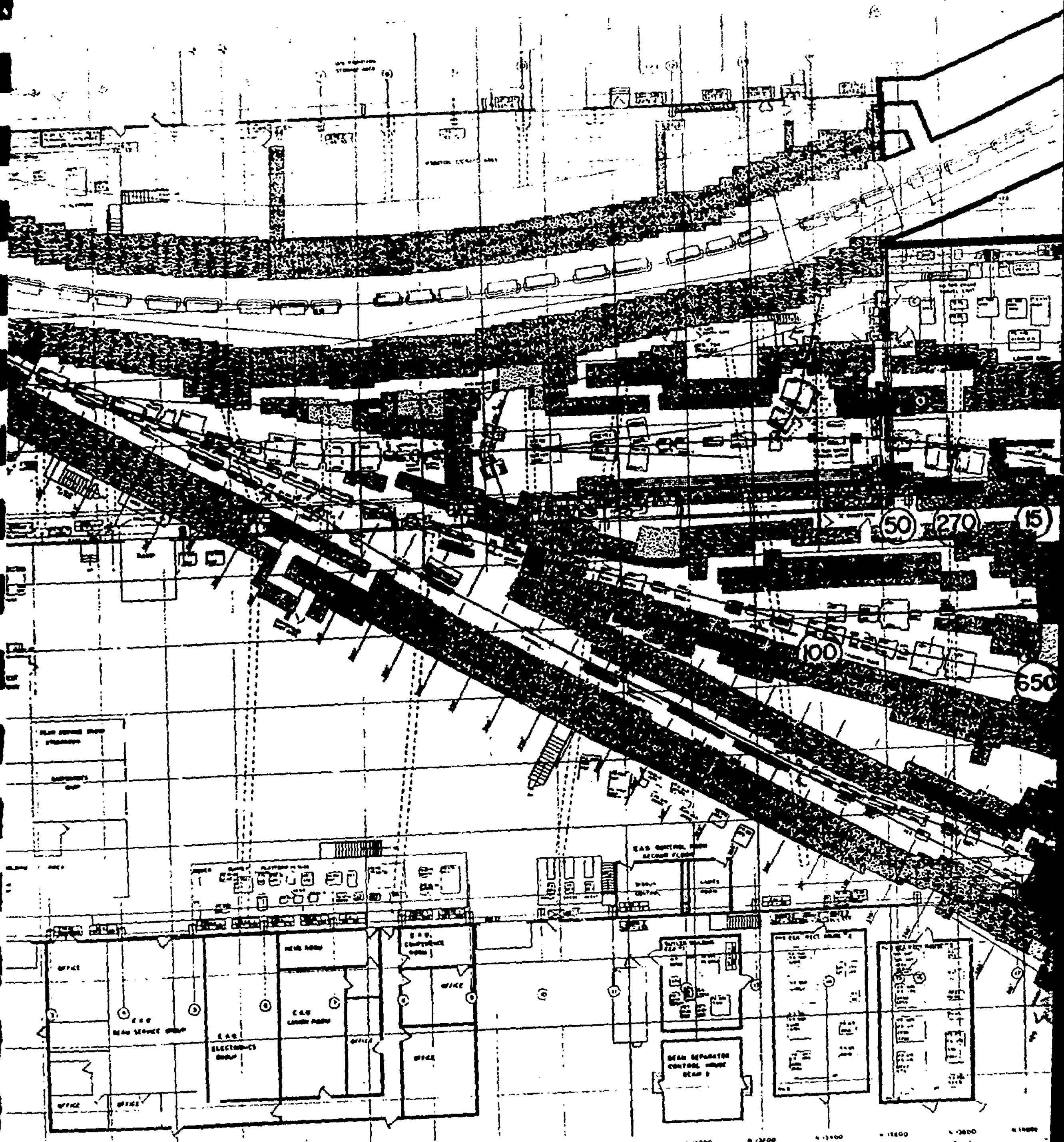
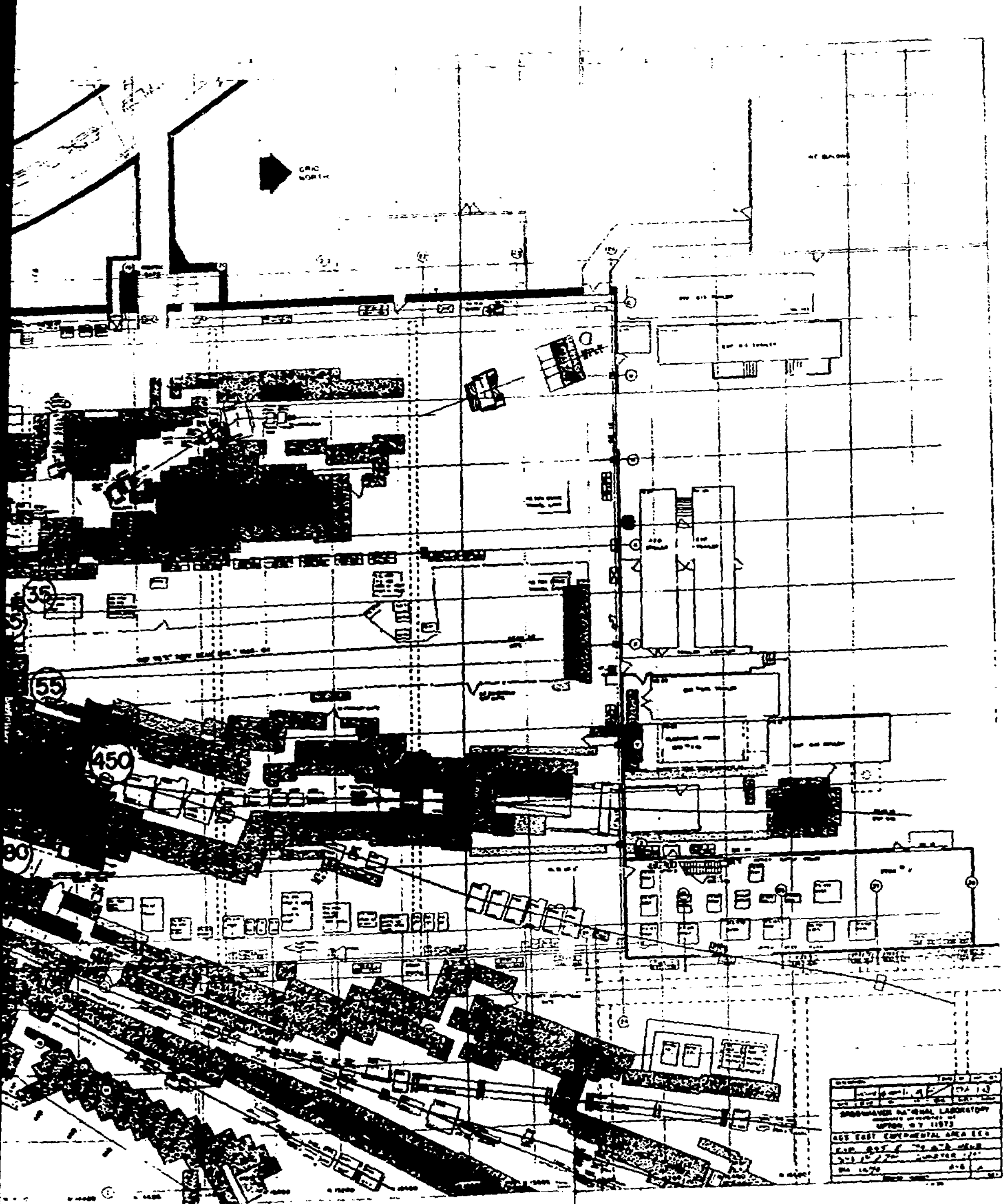


FIGURE II-2-1 THE EAST



EXPERIMENTAL BUILDING.

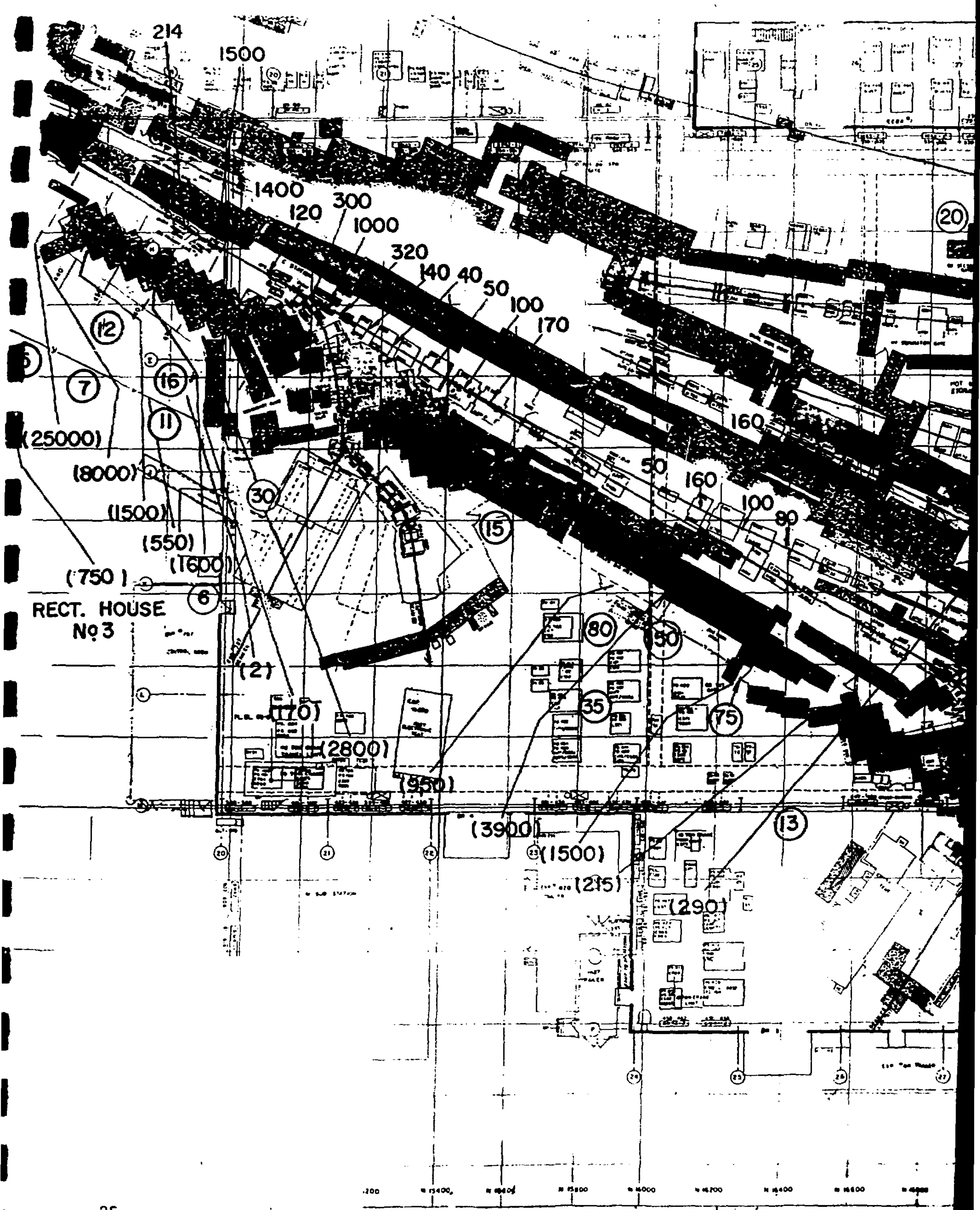
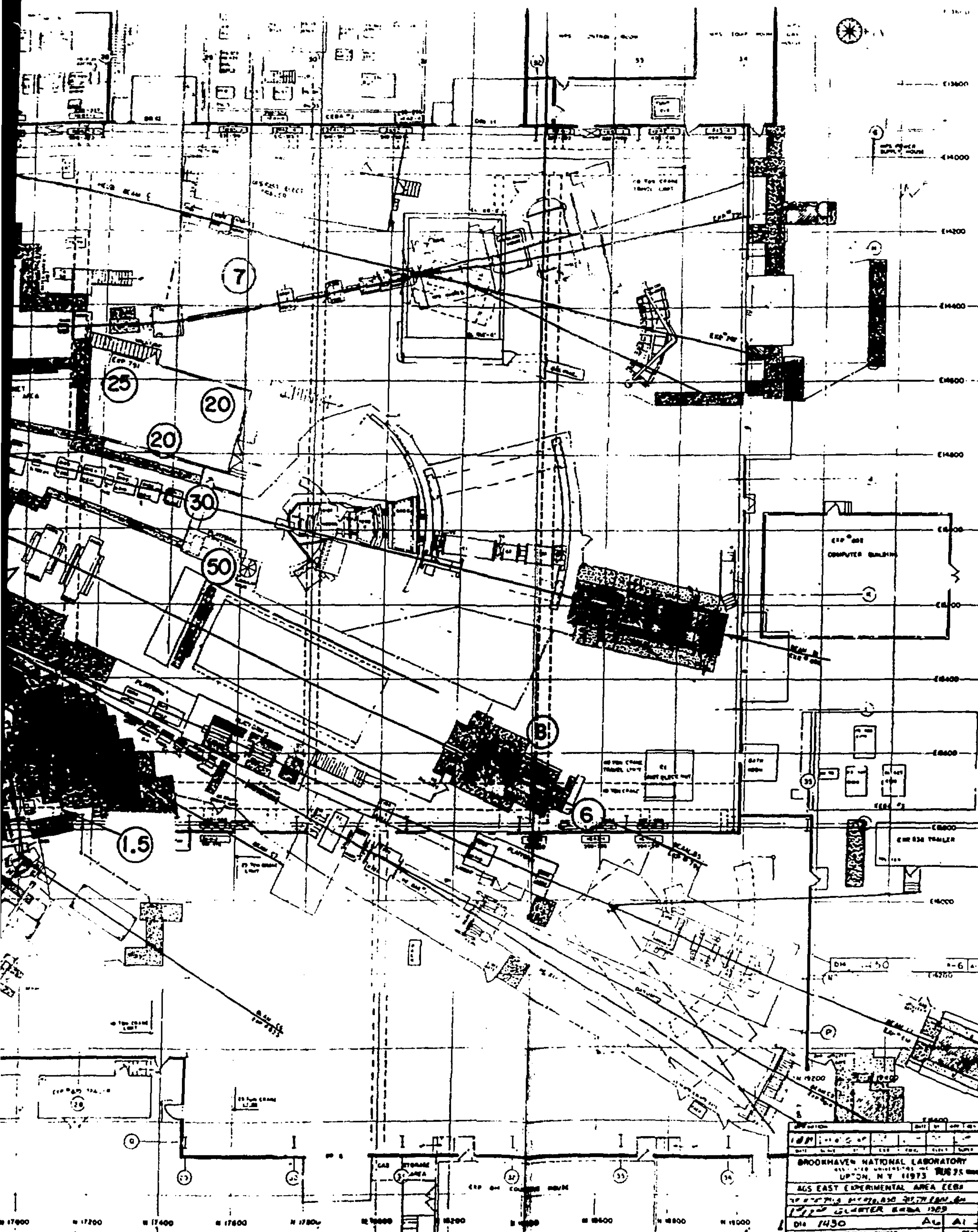


FIGURE II-3-1 THE EAST EX



ERIMENTAL BUILDING ADDITION.

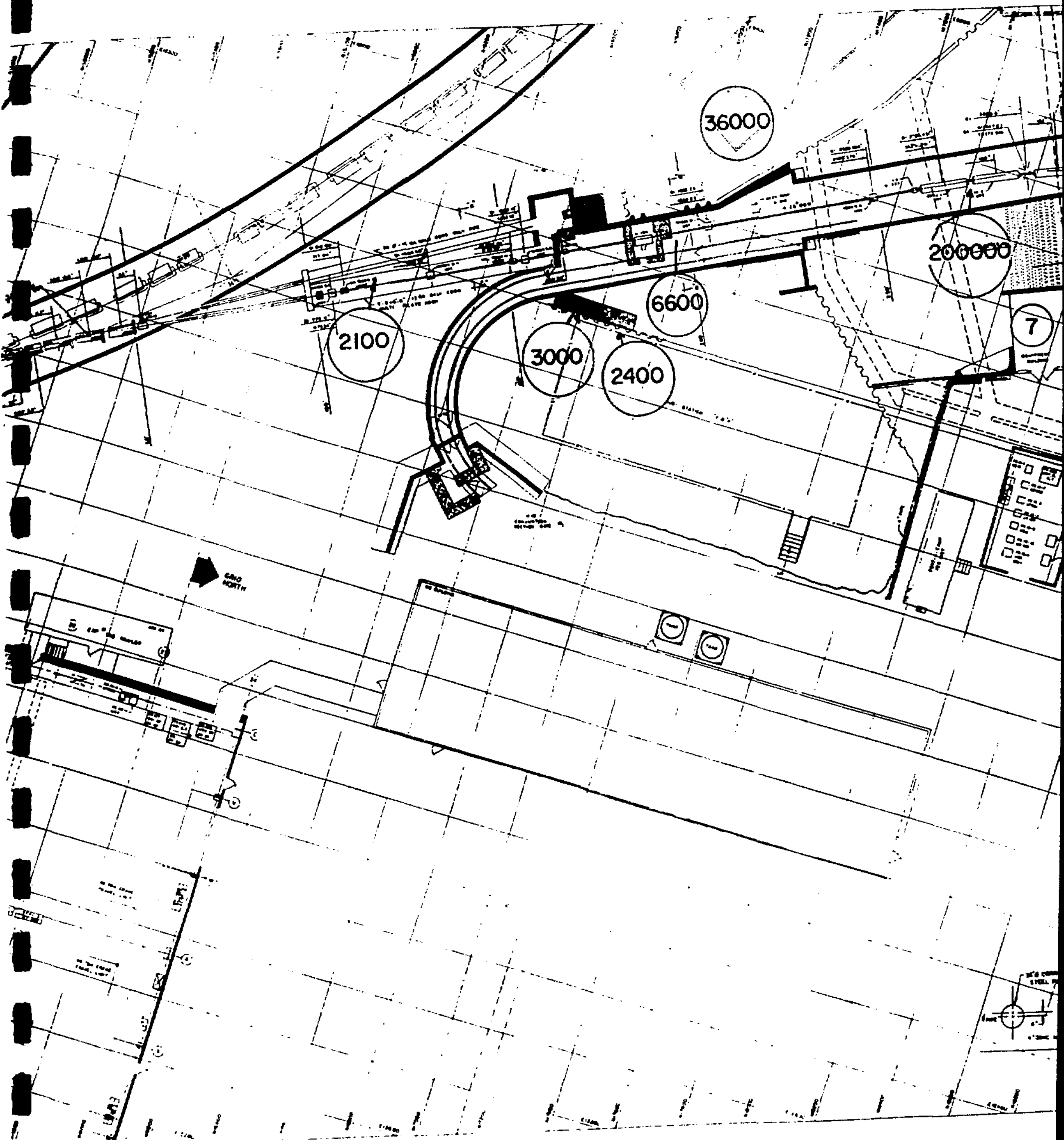
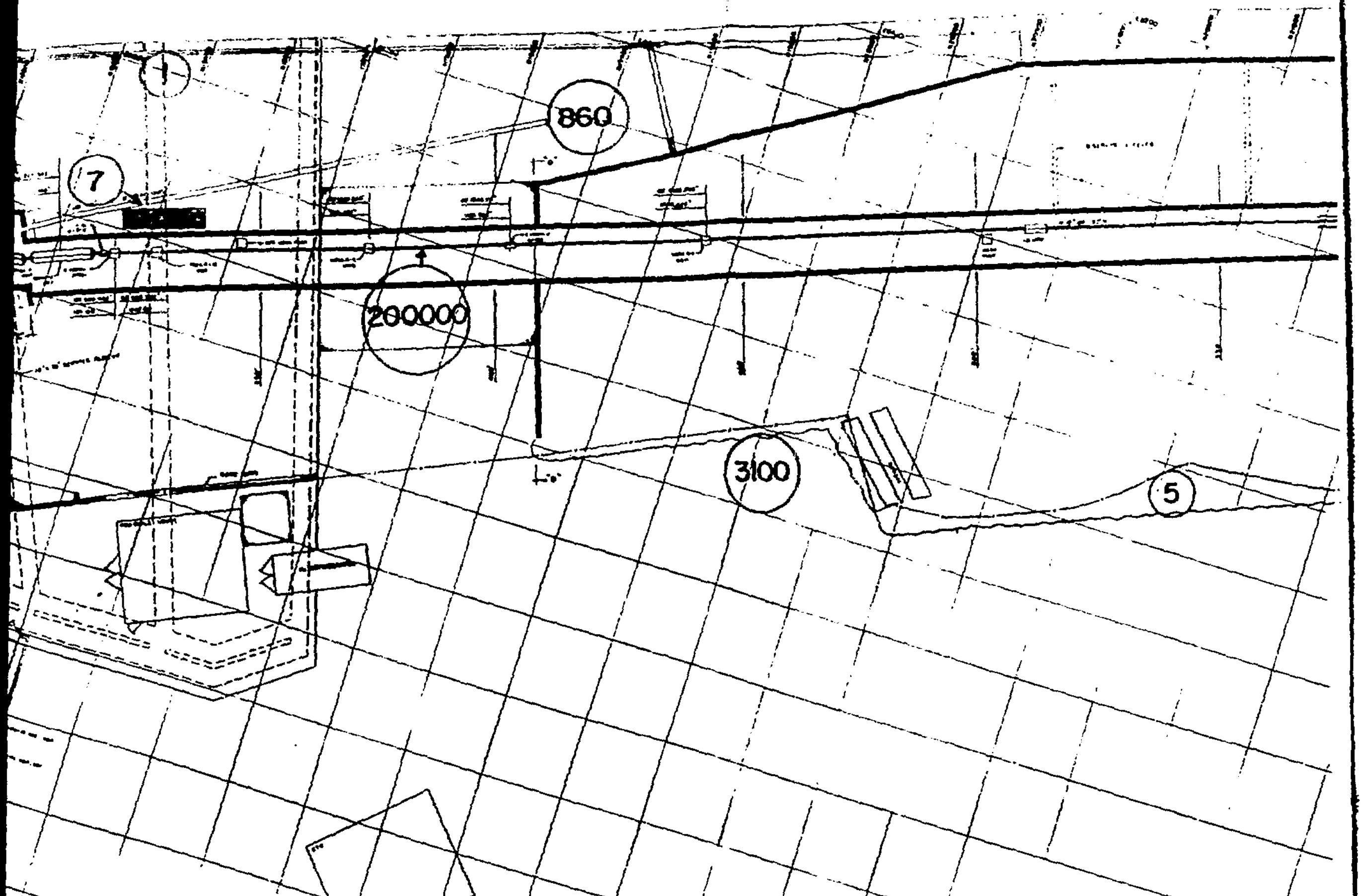


FIGURE II-6-1 THE UPSTREA



SECTION OF THE "U/V" LINE.

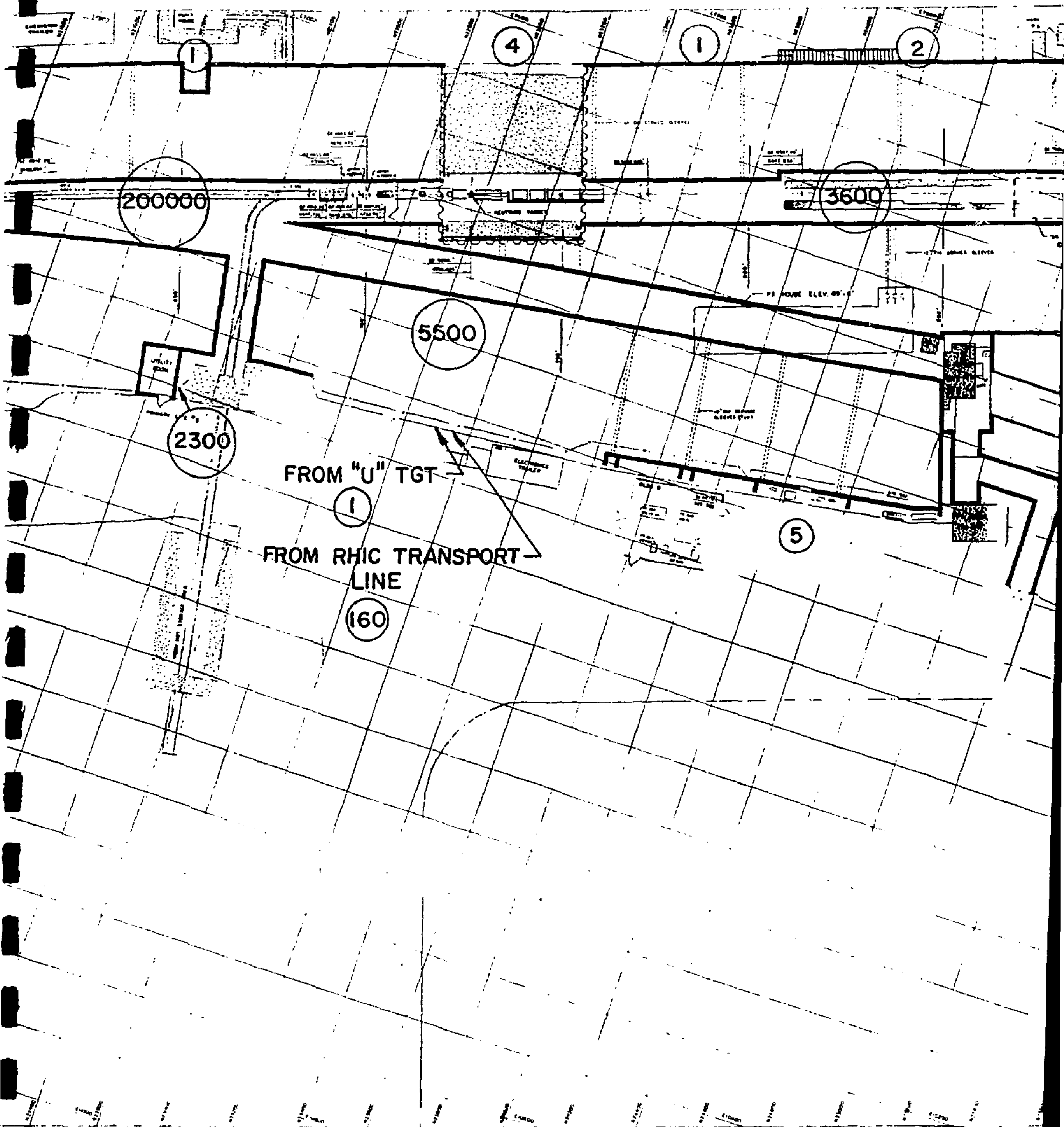
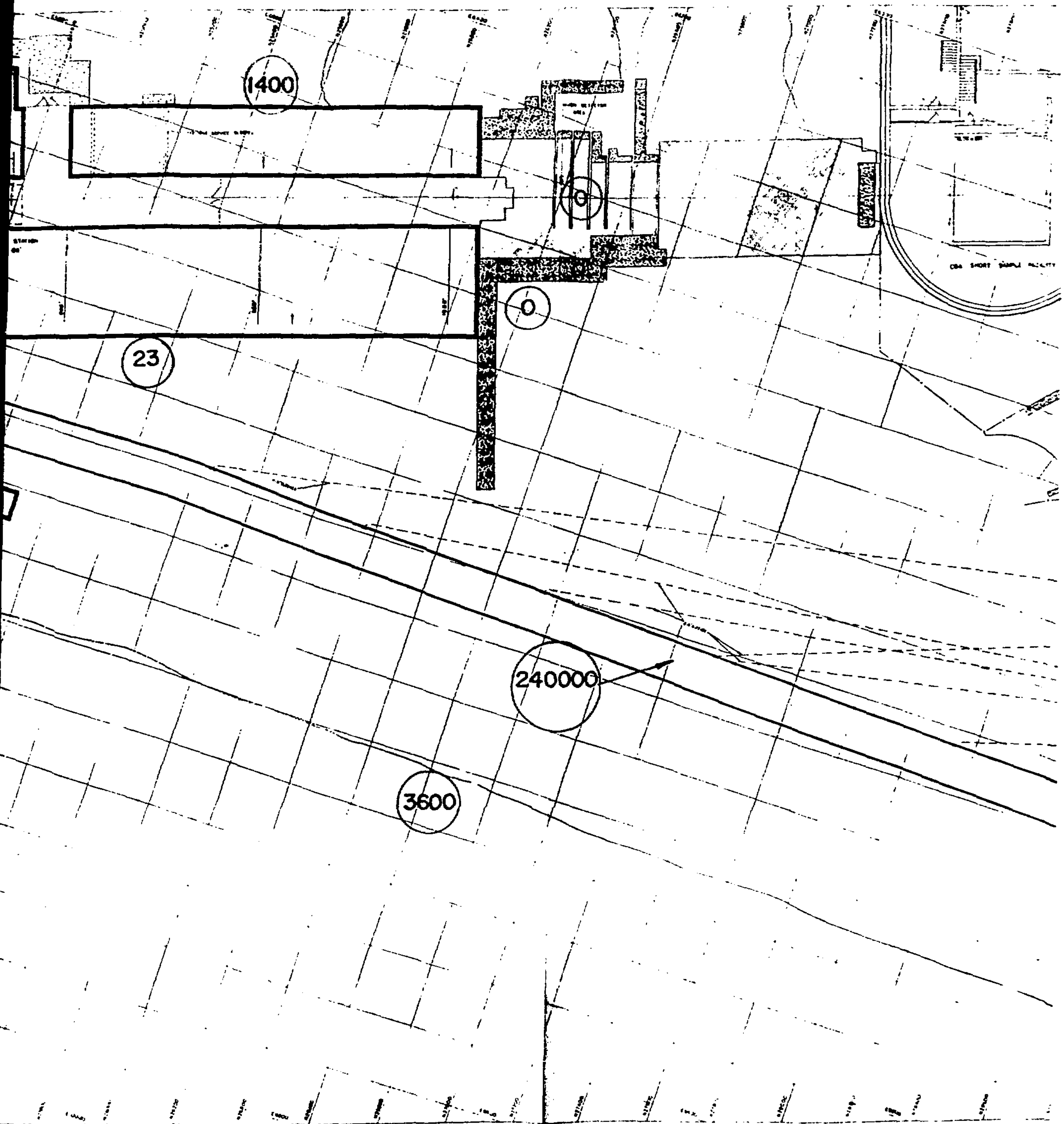


FIGURE II-6-2 THE DOWNST



EAM SECTION OF THE "U" LINE

III RADIATION MONITORING AND FAULT PROTECTION.

III-1 DESCRIPTION OF THE PRESENT SYSTEM.

Two types of radiation detectors are currently employed as security system interlock devices, CHIPMUNKS (ionization chambers) and NMC radiation paddles (scintillator/photomultiplier). Both have built in sources to indicate failure. In addition, gas-filled coaxial loss monitors are used in the accelerator ring and primary beam caves for monitoring and diagnostic purposes. The CHIPMUNKS are used as area monitors whereas the NMC paddles are used in secondary beam lines to limit intensity. Both are used to interlock beams should levels exceed limits defined by the Radiation Safety Committee.

The interlock system is hard-wired and uses relay logic to (de) activate a device such as a beam plug or magnet power supply to prevent beam from entering the fault area when a fault condition is detected. This system is monitored by an independent computer, an IBM PC, and the fault condition is logged. Relays can be reset through the PC. The fault indications from radiation paddles are also logged in the PC.

The loss monitors and the CHIPMUNKS are monitored by the AGS PDP-10 system. The CHIPMUNKS generate one digital pulse, (TTL signal), when the devices detect 2.5 microrem of radiation. The signal is counted by a Datacon scaler and read by the PDP-10 every AGS Cycle. For a level of 1 rem/hour, the CHIPMUNK generates 4×10^5 counts per hour, which is 111 counts per second. The electrical charge induced by radiation in the loss monitor is integrated by standard 4 channel integrators. The Datacon A/D digitizes the voltage through a multiplex ADC system. Again, this is done once every AGS pulse.

In general, the systems work but many problems are encountered with the CHIPMUNKS which are supported jointly by the Instrumentation Group, the Health Physics Group, the Controls Group and the Security Group. The difficulties arise from insufficient support and lack of clearly assigned responsibility for the system as a whole. The PC interlock system works well. The Safety Group looks after fault monitoring through the PC and they have been reasonably successful.

III-2 THE CHIPMUNK SYSTEM.

The CHIPMUNK scaler system is not very reliable. The Datacon Scalers are very old, and in need of upgrade. The CHIPMUNK digital signal is TTL. The number of counts per second is very small and it is very hard to analyze problems. Cables and terminations are also problems. Since there is no test signal with high enough frequency, say at least 1 KHz which is equivalent to 10 rem, it is impossible to evaluate the signal quality. Problems are often "fixed" by swapping cables with adjacent units and finding that both then work fine, but with no knowledge of how long it will last.

The other weakness is the Datacon system. The scaler module is very old, and does not work very well. There are insufficient spares. No one is responsible for supplying scaler modules for the CHIPMUNKS and maintaining the whole system.

Recommendations:

A. There should be some provision for a pulser circuit in the CHIPMUNK so that the digital system can be easily checked out.

B. A dedicated Datacon Scaler crate should be installed. The new Eurocard formatted Datacon module should be used.

C. The present Datacon system is read by the PDP-10. The data base should be reviewed such that Item B can be implemented.

D. There should be ongoing software support for the system.

III-3 THE NMC RADIATION PADDLE SYSTEM.

This system is usually used in secondary beams and has one very severe drawback; the time constant is very short. The limit is typically set according to the maximum number of particles per pulse to allowed for a given experimental area. An AGS spill is about 1.4 second of every 3.4 second cycle while the NMC unit detects average rate within a time constant less than 100 ms. A short spike of beam in the beam line will cause a trip of security system device. As far as safety is concerned, it is a fault to the safe condition, but it is a great annoyance to experimenters because of the great number of spurious trips. The system has been improved in the last few years, but is still inadequate largely due to lack of resources, both personnel and fiscal.

Recommendations:

A. The NMC units are very old and there exist two different types of unit. Personnel should be assigned to evaluate the old system.

B. The NMC unit and its paddle should be checked with a light source, such as LED pulser, to check the combined response of the NMC unit and the scintillation paddle. There exists a new NMC unit (recently purchased by the Security Group) which needs to be evaluated.

C. The maximum intensity for each beam line should be specified early. Better coordination is needed.

D. If the new NMC unit is proved to be suitable for calibration, more of them should be purchased. At least 20 will be needed to replace the existing system.

E. If possible, the time constant of the NMC unit should be lengthened. An engineering effort will be required to determine its feasibility.

III-4 THE LOSS MONITOR SYSTEM.

These devices are used for monitoring purposes and to protect equipment such as the ejection magnets F5, F10, and H20. They could also be used to provide security for the most troublesome spots in the switch-yard. It is possible to use the ionization chamber in the CHIPMUNK as a detector. These chambers have a "keep alive" source to indicate the system is functioning.

Recommendations:

A. Evaluate the merits of primary beam line intensity control with ionization chambers.

B. Use ionization chambers as loss monitors to interlock beam delivery components under fault conditions.

C. Develop and/or adapt electronics to satisfy the QA requirements for the security system.

III-5 THE EXTERNAL PROFILE MONITOR.

In Section II-1, it was pointed out that primary beam profile measurements using florescent screens temporarily inserted in the beam can lead to beam losses of one to two percent which implies as much as a

10^{12} proton per second induced point source at full intensity. Such studies would temporarily raise levels above the trip point for area monitors. As a consequence, time averaging electronics has been developed to allow brief periods at elevated levels for necessary measurements so long as the hourly rate is within guidelines. Four of these modules are needed immediately.

A alternate solution is the external profile monitor which is mounted inside the beam pipe and collects the residual ionization produced by passage of the protons to produce a beam profile for monitoring. This device does not create significant beam loss and a prototype has been tested to give beam profiles with intensities as low as 10^{12} protons per pulse. Twenty of these devices would be required to replace the flags currently used in the extracted beam.

III-6 MANPOWER, COST AND ORGANIZATION.

The Security Group only has 3 people and they are very much overloaded by operations. The wiring of the Booster security system will absorb all of their efforts. The group needs to be supplemented, or the upgrade project has to be assigned to a different group. A major problem is systems integration, especially the in the case of radiation monitoring which involves many groups. During April and May 1990, the CHIPMUNK setup involved HP, Instrumentation, the Security Group, and Main Control Room personnel. One particular group has to be responsible for insuring that the system is functioning properly.

A. <u>The CHIPMUNK system</u>:

CHIPMUNKS:	$5K each complete. $100K needed to complete 20 in FY 91.
Datacon Scalar:	$30K
Technician:	1.75 man-years, $123K. This includes construction testing and future installation.
Engineer:	.5 man-year, $45K. Design and upgrade of the CHIPMUNK system, e.g. testing circuit for the CHIPMUNK to check out the digital system.

New control system: Use a dedicated Datacon loop with the new Apollo Datacon System. Computer and Datacon driver system, $15K. .5 man-year of the software effort, $40 K. total $55K.

Subtotal $353K

B. A New NMC System:

New NMC: $3 K each. Require 20 for total operation. Total cost, $60K.

Engineer: .5 man-year for calibration and test system, $40K.

Technician: 1 man-year. For new paddles, inter-lock boxes, and the cables between the paddle and the NMC boxes, $35K.

Subtotal Cost $135K

C. A New Intensity Control Device.

The present method of dealing with intensity excursions is with the NMC paddle as a detector for experimenter controlled beams, i.e. HEP secondary beams and HIP primary beams. In order to limit primary proton beam intensities with the Booster in operation, new devices must be employed. For some beam lines, the ability to set a reliable intensity limit can eliminate the necessity of shielding for the full Booster intensity. Once this kind of system is developed, it can also be used to interlock critical devices in the switchyard. The new system should directly detect the source of loss and should not completely rely on the CHIPMUNK outside the Switchyard Cave. An ionization chamber based loss monitor system for the detector appears to be the best choice at the present time. The electronics must satisfy the QA requirement, i.e. fail safe. Los Alamos has designed a system like this. An estimate of the cost of a system based on this is $5K per device.

1. Primary beam interlock: 6 beam lines, with redundant detectors, requires 12 units. Cost $60K.

2. Switchyard devices: It is necessary to determine which com- components to interlock with this system. Twenty detectors are required at $5K each or $100K.

3. Engineer: .5 man-years, $40K.

4. Technicians: 1-man year, $70K.

Subtotal Cost: $270K

D. Time Averaging Electronics and the External Profile Monitor.

1.	4 time averaging electronic modules at $3.3K each	$ 13.2K
2.	20 external beam monitors with associated electronics at $10K each	$200K
	Subtotal	$213K
	TOTAL COST	$961K

IV DESIGN GUIDELINES FOR THE PLANNED ACTIVATION OF SOIL/WATER AND AIR.

This section describes the design guidelines for on- and off-site soil and air activity concentrations. These concentration guides keep AGS operations within prescribed dose limits. A variety of guidelines apply at BNL and they are as follows.

IV-1 SOIL AND WATER CONTAMINATION.

1) For ingestion, the design guidelines are:

a) where the facility radioactive liquid effluent exceeds 5 times the Derived Concentration Guides (DCG) of DOE Order 5400.5, one shall perform an evaluation of best available technology for reduction of radioactive emissions (BNL OH&S Guide 3.3.0). The DCG for ^3H is 2×10^6 pCi/L, and the DCG for ^{22}Na is 1×10^4 pCi/L, and each DCG corresponds to 100 mrem/y for drinking from a contaminated water supply, and

b) off-site drinking water concentrations shall deliver 4 mrem/y or less to an individual living off-site, or less than the New York State Drinking Water Standard (NYSDWS), whichever is less. The NYSDWS for ^3H is 2×10^4 pCi/L which corresponds to 1 mrem/y, and the concentration which corresponds to 4 mrem/y for ^{22}Na is 4×10^2 pCi/L, and

c) the administrative limit from the Director's Office for ^3H concentration in the sanitary-sewer liquid effluent is 1×10^4 pCi/L.

Design guideline 1a) is new since it restricts the contamination levels in water in soil near a facility. Because on-site soil is proximate to target stations, this is the most restrictive guideline to date.

2) For inhalation, the design guidelines are:

a) one must avoid exposure of personnel to inhalation of airborne radioactive materials under normal operating conditions to the extent reasonably achievable. One must accomplish this by using confinement and ventilation (DOE Order 5480.11), and

b) where airborne effluents are a result of operations, one shall consider reducing emissions to less than 0.1 mrem/y for site boundary exposure (BNL OH&S Guide 3.3.0).

Approach:

In order to demonstrate how an effluent analysis for a target station was performed, a design was assumed Fig.IV-1-1.

This assumed design has a variety of characteristics which illustrate several problems. It was not intended to replace a separate analysis for each future target station. The following was also assumed:

a) a running period of 20 weeks/y

b) 5×10^{13} protons/pulse

c) 1 pulse every 2.5 seconds for an average of 2×10^{13} p/s on target, and

d) a 1 cm thick iron target.

Ingestion Analysis:

Contamination In Soil Which Is Near The Target

The systematics of spallation have been worked out by Van Ginneken.[IV-1] Based on a Monte Carlo program named CASIM, Beavis[IV-2] estimated the production of ^3H and ^{22}Na in soil around the target and dump. The Beavis value of 0.075 ^3H atoms/soil-star was in agreement with measured the value of 0.066 ^3H atoms/soil-star.[IV-3]

Based on the report by Beavis, the maximum production rates of ^3H and ^{22}Na integrated over all soil were:

$$0.3527\ ^3H/p \times 2 \times 10^{13}\ p/s = 7.1 \times 10^{12}\ ^3H\ \text{atoms/s, and}$$

$$0.09066\ ^{22}Na/p \times 2 \times 10^{13}\ p/s = 1.8 \times 10^{12}\ ^{22}Na\ \text{atoms/s.}$$

For cylindrical geometry, the mean volume which contained this contamination was estimated from the radius of soil through which the CASIM star concentration was reduced by a factor e. This radius was taken to be perpendicular to the proton beam path.

From the Beavis report, the highest concentration of CASIM stars was in the 500 cm of soil past the target, which was the transport tube area indicated in Figure IV-1-1. Soil this close to the target maximizes contamination. For this soil, most contamination was contained within a cylinder with an inside radius of 30 cm, an outside radius of 51 cm and a 500 cm length.

The next highest concentration was in the soil surrounding the last 500 cm of the target cave. This soil was separated from the target by 60 cm of heavy concrete. A similar cylinder, 2 of 60 cm inner radius and 278 cm outer radius, was estimated to contain the contaminated soil surrounding the target cave.

The third highest concentration was in the soil surrounding the first 500 cm of the beam dump. This soil was separated from the primary proton beam by of 150 cm of iron. A cylinder of 150 cm inner radius and 178 cm outer radius was estimated to contain the contaminated soil surrounding the beam dump.

The mean volumes of contaminated soil were 2.7×10^6 cm^3 around the transport tube, 1.5×10^7 cm^3 around the target cave, and 1.4×10^7 cm^3 around the beam dump.

Assuming that 90% of all soil radioactivity was in soil around the beam transport tube, which was reasonable based on the Beavis report, the atom production rates per unit volume of transport tube soil were:

2.4×10^6 ^3H atoms/cm^3s, and

6.0×10^5 ^{22}Na atoms/cm^3s.

Assuming that the ^3H and ^{22}Na were completely leachable and assuming that the soil was 10% water by volume,(IV-4) the atom production rates per unit volume of soil water were:

2.4×10^{10} ^3H atoms/Ls and

6.0×10^9 ^{22}Na atoms/Ls.

Radioactive decay removes the ^3H from the soil water at the instantaneous fractional rate of 0.0561/y, and the ^{22}Na at the rate of 0.34/y. The other removal process of importance is that due to rain water percolating downward through the soil.

Rain water falls to the soil surface at the rate of 55 cm/y, and travels downward 10 to 20 m below the surface before reaching ground water.(IV-3) The 21 cm radius of contaminated soil around the beam transport tube, which was 42 cm thick for rainfall passing above and below the transport tube, contained 10% or 4.2 cm of water. Thus, in the course of a year, the contaminated soil water was recharged at the instantaneous volume replacement rate of 13.1/y. At equilibrium, the activity concentration in soil water equals the activity production rate per unit volume of soil water divided by the sum of the removal rate constants (e.g. $0.0561 \times 2.4 \times 10^{10}/[13.1 + 0.0561]$ for ^3H). A similar analysis was used for the soil around the target cave and the beam dump. Based on the atoms in soil per incident proton computed by Beavis, the soil surrounding the target cave contains 9% of the total radioactivity in soil, and the soil surrounding the beam dump contains 1%. The equilibrium activity concentrations in soil water near these locations were given in Table IV-1-1.

TABLE IV-1-1

Origin of Contamination	Activity Concentration in Water in Soil Near Target		Number of DCGs	
	^3H pCi/L	^{22}Na pCi/L	^3H	22Na
Soil Around Beam Transport Tube	2.8×10^9	4.1×10^9	1.4×10^3	4.1x105
Soil Around Target Cave	4.9×10^7	7.4×10^7	2.5×10^1	7.4×10^3
Soil Around Beam Dump	5.8×10^6	8.8×10^6	2.9×10^0	8.8×10^2

Except for soil water near the beam dump for ^3H, these concentrations exceed 5 DCGs. The values in Table IV-1-1 indicate the concentration of ^{22}Na is the most restrictive parameter which the AGS must control on site. Adding heavy concrete between the soil and the source will control this problem as follows.

The Beavis report indicated that the concentration of stars in heavy concrete falls off according to:

$$C = C_0 \, (r_0/r)^2 \, e^{-0.045x}$$

where

r_0 = radial distance at which the initial star concentration C_0 occurs in heavy concrete,

r = radial distance at which the star concentration diminishes to C, and

x = thickness of heavy concrete (cm).

Thus, an additional 92 cm of heavy concrete is needed around the beam dump in order to reduce the concentration of ^{22}Na from 880 DCGs to 5 DCGs, an additional 142 cm was needed around the target cave, and an additional 167 cm was needed around the transport tube.

<u>Contamination Off-Site</u>:

Contaminated water in local soil around the target area moves downward with rainfall. Once it joins the water table, it moves downward and southeasterly to the site boundary at 3 km, mixing along the way. The initial vertical movement varies but could take a day or two before reaching the water table with normal rainfall. The shape of the contaminated volume at or below the water table depends on the rate at which the contaminated rain water arrives. For 20 weeks of continuous running and normal rainfall, a ribbon of contamination a few m wide, tens of m long and a few cm thick would initially form in sand.[*IV-4*] However, due to heterogeneities in permeability, and due to fracturing and stratification in an aquifer the size of the BNL site, considerable dispersion occurs over distances which extend to the site boundary.

The degree of dispersion is characterized by using Equation 4.48 and the parameter values given in Reference *IV-5*:

$$D_L = R_d 4\pi n_e x b(\alpha_L \alpha_T)^{0.5}/FV_T e^{-\beta t}$$

where

D_L = minimum dilution, initial concentration divided by the concentration at x,

R_d = retardation coefficient, 1 for ^3H and 1 for ^{22}Na for sand,

n_e = effective porosity, 0.32 for sand for Long Island glacial deposits,

α_L = horizontal dispersivity, 2130 cm for Long Island glacial deposits,

α_T = the vertical dispersivity, 430 cm for Long Island glacial deposits,

b = the thickness of the aquifer, variable from 5000 cm to 30,000 cm for Long Island aquifer,

x = the distance down gradient of the release, 300,000 cm to the site boundary,

V_T = volume of liquid source term. Assuming that contaminated soil water recharges from rainfall at the instantaneous rate of 13.1/y, the annual volumes of the liquid source term are:

a) 3.5×10^3 L near the transport tube,

b) 2.0×10^4 L near the target cave,

c) 1.8×10^4 L near the beam dump, and

for this analysis, 2.0×10^4 L is used in order to minimize the estimate of D_L.

β = radioactive decay constant in y^{-1},

t = travel time to the site boundary, 20.5 years. This is determined from xR_d/U where U is 0.4 m/day for Long Island glacial deposits, and

F = 1.2 for $b^2/\alpha_T x = 7$ (see Figure 4.8 of Reference IV-5).

For contamination in soil water near the source at or below 5 DCGs, Table IV-1-2 indicates the resulting off-site contamination levels in ground water.

TABLE IV-1-2

Nuclide	Concentration in Soil Water Near Source (5 DCGs)	Minimum Dilution, D_L	Concentration in Ground Water Off-site	Off-site Limit
	pCi/L	#	pCi/L	pCi/L
^{3}H	$1x10^{7}$	$7.6x10^{5}$	$1.3x10^{1}$	$2x10^{4}$
^{22}Na	$5x10^{4}$	$2.6x10^{8}$	$1.9x10^{-4}$	$4x10^{2}$

In summary for the soil under the AGS experimental floor, any design which limits concentrations to no more than 5 DCGs will also limit concentrations for ^{3}H or ^{22}Na in ground water off-site to safe levels.

IV-2 AIR CONTAMINATION.

Inhalation Analysis.

On-Site Exposure

The following atom loss rates and the atom production rates were used to estimate the instantaneous time rate of change of radioactive atoms in air:

$$dN_i/dt = - \beta_i N_i - k N_i + P_i \text{ , or}$$

$$N_i = P_i [1-e^{-(\beta_i+k)t}]/(\beta_i + k)$$

where:

N_i = the number of atoms of nuclide i in air at time t, atoms,

β_i = instantaneous fractional removal rate of nuclide i due to radioactive decay in s^{-1},

P_i = production rate of nuclide i in atoms/s, and

k = instantaneous fractional removal rate of nuclide i due to ventilation in s^{-1}.

For uniform instantaneous mixing, the activity concentration in target cave and beam line air was given by:

$$A_i = 2.7 \times 10^{-5} \beta_i N_i = 2.7 \times 10^{-5} \beta_i P_i [1-e^{-(\beta_i+k)t}]/[(\beta_i+k)V]$$

where:

A_i = the activity concentration, $\mu Ci/cm^3$, and

V = volume of air in typical target cave and typical beam line, 1×10^9 cm^3.

For 20 weeks of continuous running, the activity concentrations in the target cave and beam line system were listed in Table IV-2-1. They were estimated from the atom production rates given by Beavis in Reference *IV-6*. It is assumed the ventilation system is capable of changing the beam line and target cave air volume three times per hour; that is, $k = 8.3 \times 10^{-4}$/s.

TABLE IV-2-1

Nuclide	Atom Production Rate, P_i	Decay Constant, β_i	Activity Concentration In Tunnel, A_i	Derived Air Concentration (DAC)
	atoms/s	s-1	$\mu Ci/cm^3$	$\mu Ci/cm^3$
^{41}Ar	1.9×10^9	1.1×10^{-4}	6×10^{-6}	5×10^{-5}
^{35}S	1.0×10^8	9.2×10^{-8}	3×10^{-10}	7×10^{-6}
^{32}P	1.3×10^8	5.6×10^{-7}	2×10^{-9}	2×10^{-7}
^{28}Al	5.0×10^7	5.2×10^{-3}	1×10^{-6}	a
^{22}Na	5.0×10^7	4.9×10^{-9}	8×10^{-12}	3×10^{-7}
^{15}O	7.5×10^9	5.7×10^{-3}	2×10^{-4}	a
^{14}O	2.0×10^8	9.4×10^{-3}	5×10^{-6}	a
^{13}N	9.0×10^9	1.2×10^{-3}	1×10^{-4}	a
^{11}C	8.0×10^9	5.6×10^{-4}	9×10^{-5}	2×10^{-4}
^{7}Be	8.0×10^9	1.5×10^{-7}	4×10^{-8}	8×10^{-6}
^{3}H	2.7×10^{10}	1.8×10^{-9}	2×10^{-9}	2×10^{-5}

a No DAC listed in DOE Order 5480.11.

The Derived Air Concentrations (DAC) listed in Table IV-2-2 for each nuclide correspond to 2.5 mrem/h. Thus, the total dose rate is a fraction of a mrem/h except for the contribution of the very short-lived nuclides ^{28}Al, ^{15}O, ^{14}O, and ^{13}N. The dose rate from these short-lived nuclides was taken as 1.5 x 10^6 mrem/h per μCi/cm^3. Thus, ^{15}O and ^{13}N approach several hundred mrem/h in the tunnel, at least until the primary beam is off. Waiting 15 minutes prior to entry to the tunnel system will reduce the air concentration of these nuclides to negligible levels due to decay and ventilation.

Off-Site Exposure.

The weather conditions which lead to a maximum off-site dose equivalent from a release of beam line and target cave air were used here. Thus for the AGS, the ratio of maximum off-site air concentration to activity release rate was assumed to be 1 x 10^{-10} s/cm^3. The activity release rate was determined from the product of air concentration, Ai, and the flow rate. The flow rate is the product of kV, which is 8.3 x 10^5 cm^3/s. By estimating the maximum activity concentration for an off-site location, one can compute the maximum dose equivalent from internal exposure for 20 weeks of continuous running.[IV-7] The activity release rates, the maximum off-site air activity concentrations, and the maximum dose equivalents to a person at the location of maximum concentration for 20 weeks are listed in Table IV-2-2.

TABLE IV-2-2

Nuclide	Tunnel Activity Release Rate[a]	Maximum Off-Site Concentration[b]	Maximum Off-Site Dose Equivalent[b]
	μCi/s	μCi/cm^3	mrem
^{41}Ar	5.0x10^0	5.0x10^{-10}	8x10^{-2}[c]
^{35}S	2.5x10^{-4}	2.5x10^{-14}	3x10^{-5}
^{32}P	1.7x10^{-3}	1.7x10^{-13}	7x10^{-3}
22Na	6.7x10^{-6}	6.7x10^{-16}	2x10^{-5}
^{11}C	7.3x10^1	7.5x10^{-9}	2x10^{-1}
^{7}Be	3.3x10^{-2}	3.3x10^{-12}	3x10^{-3}
^{3}H	1.7x10^{-3}	1.7x10^{-13}	7x10^{-5}

a ^{28}Al, ^{15}O, ^{14}O and ^{13}N were removed from contaminated air due to decay in transit to site boundary.
b For a 20-week running period.
c Immersion dose equivalent.

In summary, if one factors into account wind direction for a 20 week period, off-site exposure will not be in excess of design guideline 2b for any individual. On-site exposure should be avoided by waiting a predetermined period after the beam has been shut off, thus satisfying guideline 2a.

It was assumed that radioactivity levels in the air in target cave and beam line were reduced by using three air changes per hour. Removing the air locally near the target in order to reduce worker exposure and/or using a delay line or filter in order to eliminate off-site exposure are other approaches to consider. Eliminating air in the primary beam path also reduces the production of airborne radioactivity.

Conclusion

In summary for future running at 5×10^{13} protons/pulse in any beam line, control of on-site soil water concentrations to below 5 DCGs requires the thickness of heavy concrete which separates typical targets and nearby soil to be 167 cm (5.5 ft). For a typical 1.5 m radius iron beam dump, a 92 cm (3 ft) outer layer of heavy concrete must be present between the source and the soil. The requirement to control on-site soil water concentrations also impacts on other high loss points as well. For example, we must ensure that the heavy concrete shields around the proposed AGS scraper/internal dump, the extraction septum, the new D-target station, the g-2 target station, and chronic loss points such as the Lambertson magnets are sufficient to meet guidelines for the ingestion hazard.

One can avoid worker exposure to contaminated air under normal operating conditions providing that delay before entry into primary areas is a standard operating procedure, and/or providing that ventilation is used. Based on the planned level of operations, realistic estimates of off-site dose equivalent were less than 0.1 mrem/y to any individual due to vented contaminated air.

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Figure Caption

Figure IV-1-1 TARGET STATION MODEL FOR SOIL ACTIVATION CALCULATIONS.

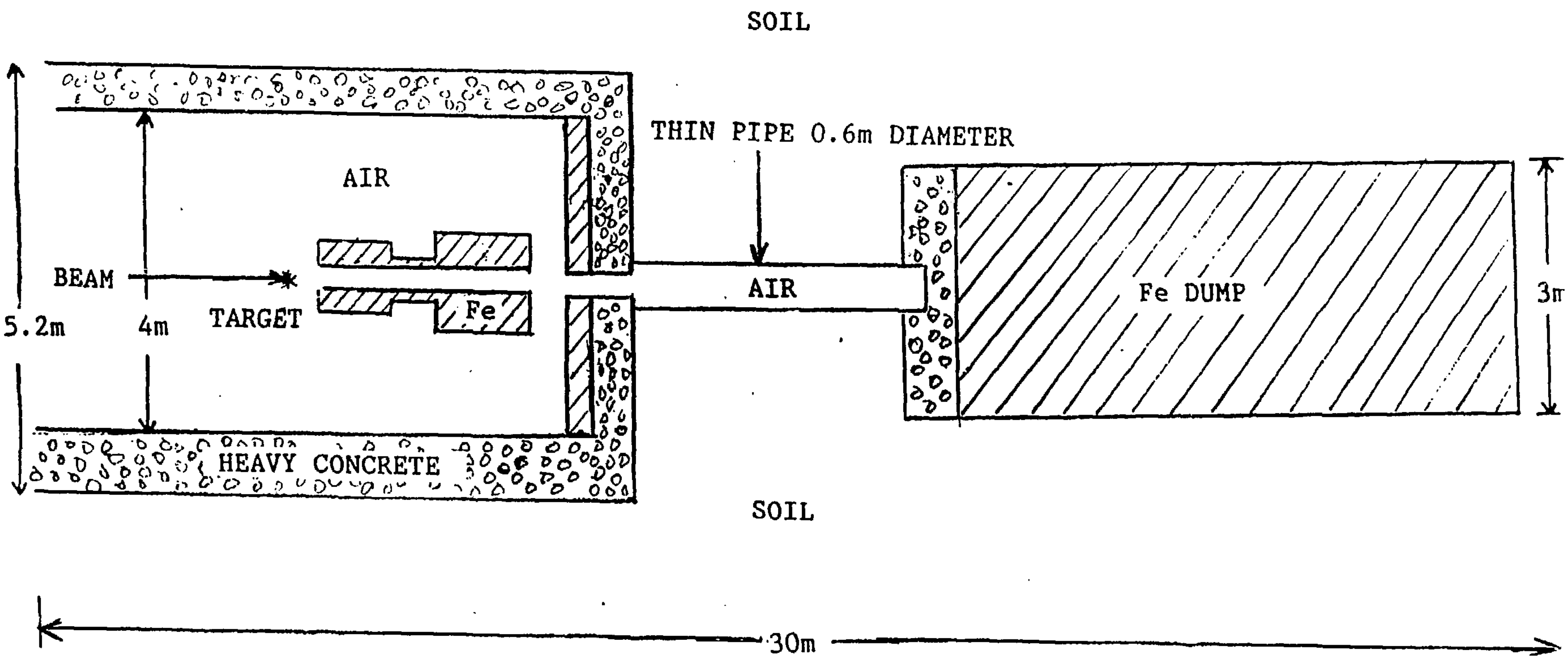

FIGURE IV-1-1 TARGET STATION MODEL FOR SOIL ACTIVATION CALCULATIONS

V SUMMARY.

This report has dealt with the consequences for radiation safety of bringing 5 x 10^{13} protons per pulse to each of the target stations. With the possible exception of the "U/V" Lines there is little likelihood of normal operation with more than 2 x 10^{13} per pulse in any of the existing primary beams in the next five years. Pressure for more intensity arises from sharing the total intensity between five target stations in the East Experimental Area during Slowly Extracted Beam operation as individual experiments approach the ability to handle secondary beams generated by 1 x 10^{13} protons per pulse on target. It is anticipated that the AGS Booster will eventually allow the acceleration and extraction of more than 6 x 10^{13} protons per pulse compared with the present 1.6 x 10^{13} that is presently available.

Experiment 821, a measurement of the anomalous magnetic moment, g-2, of the muon will have the capacity to accept all the accelerated beam. The primary beam "U", target station and secondary beam are presently being designed. The experiment is scheduled to begin testing with beam in FY1994 and data collection in FY1995. The shielding design should permit full intensity operation.

If the neutrino program, which takes the entire AGS extracted beam in a two second cycle, were to resume with a proposal for a major new experiment, the "U" Line would have to be upgraded as it is clearly inadequately shielded for Booster era intensities.

Eliminating known problems in the East Experimental Area will cost nearly $3.5M in material and labor. Even if this amount of money were made available at once, crane conflicts and interference with the experimental program would result in a time scale of several years for completion. The plan for carrying out the upgrade is to first eliminate those problems that are significant at present AGS intensities followed by those that are less serious. Trench and column shielding improvements can yield larger reductions in external radiation than magnet replacement at similar cost. An instrumentation upgrade costing $.96M could go on in parallel so that those areas that have not been upgraded could be closely monitored to prevent unanticipated intensity excursions. This effort will have long term consequences since good monitoring, fault detection and beam control are essential for safe and efficient operation of the AGS Complex.

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