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Shielding for the AGS J10 Scraper

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Technical Note

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I. SUMMARY

This note documents the design of the shielding which will be installed at J-10 in the AGS tunnel to shield the new AGS scraper

II. INTRODUCTION

Section III develops from the literature formulas for predicting the induced activity around the scraper. Section IV reports the ALARA guidelines for effluents. Section V uses the formula of Section III to demonstrate that the local shielding specified for the scraper meets the ALARA guidelines.

III. CALCULATION OF THE LONG-LIVED INDUCED ACTIVITY IN THE SOIL AROUND THE AGS J10 SCRAPER

This section is based on reference 1 which calculated the distribution of all the long lived radio-isotopes produced in the soil surrounding a lead target bombarded by 10^{13} protons per second for 25 years. The only two nuclides that approach the ALARA guidelines are tritium, ^{3}H, and sodium 22, ^{22}Na, the others being either short lived, of low yield, or not leachable. Table 1 summarizes the pertinent results from Table III of reference 1.

In order to generalize these results we make certain assumptions.

a.) The activity falls off as a function of radius. We assume cylindrical geometry applies and that the activity falls off as 1/r.

b.) The activity falls off as a function of the distance (often called the mass density thickness) measured in terms of mass per unit area, that is as a function of the integrated amount of side-shield material between the beam center line and the measurement point.

c.) The activity production is independent of the kind of side-shield material but is proportional to the density of the material.

d.) The activity is proportional to the proton energy to the 0.8 power.

e.) This calculation is taken longitudinally only for that one meter length where the activity is at a maximum. Averaging over a greater longitudinal distance would reduce the calculated activity.

In order to determine the function in assumption b.), we multiply the activities in Table 1 by the mean radius of each annular region and scale the first point by the ratio of the densities of soil to concrete. The results are given in Table 2 and plotted in Figures 1 and 2. For ^{22}Na the activity as a function of radius and shielding density is given by:

$$y(r) = I*[(E/3)^{0.8}]*[\rho(r)/1.8]*[(1.82E\text{-}04)/r]*\exp\{-9.33E\text{-}3*x(r)\}$$

where:

r	=	radial distance from source to measurement point in centimeters
y(r)	=	activity of ^{22}Na in Curies per cubic centimeter at radius r
I	=	steady state proton intensity incident on the scraper in units of 10^{13} protons per second
E	=	proton energy in GeV
ρ(r)	=	density in grams per cubic centimeter at r
x(r)	=	integrated material from source to r in grams per square centimeter

The equation for tritium is very similar but the tritium concentration is not as limiting as the ^{22}Na concentration. Appendix I gives the 1/e fall-off of the ^{22}Na activity for various shielding materials.

IV. ALARA GUIDELINES

The As Low As Reasonably Achievable (ALARA) guidelines for the concentration of activities in the soil water around the scraper enclosure are given in Table 4.1.2.a of reference 2. They are 1E-08 Curies per cubic centimeter for tritium and, most importantly, 5E-11 Ci/cc for ^{22}Na.

V. SHIELDING DESIGN

The scraper is designed to have 55 centimeters of iron around the impact point with in general 350 centimeters of drift space to the tunnel wall which is on average 35 centimeters thick. Assume a 24 GeV beam energy. Assume an annual average beam intensity equivalent to that achieved in FY 1995 of 0.5E13 protons per second and assume that averaged over a year 5% of this beam winds up in the scraper. Then the equation above can be used to calculate the results shown in Figure 3 which shows that the activity in the first few centimeters of soil outside the tunnel is 3.3E-10 Ci/cc. The activity concentration in the effluent water from the soil around the tunnel which will be produced by this level of activity in that soil is calculated in Table 3. Only 7.5% of the ^{22}Na produced in the soil is leachable.[3] Ten per cent of the soil is water which gives a concentration factor of ten. However a calculation based on some simple geometrical assumptions gives a dilution factor of 9. The activity in the soil falls off by 1/e in 60 centimeters. Assume that water flowing through this area passes on the average through 60 centimeters of activated soil. The fraction of water in the soil is 10 %, as above, which gives 6 centimeters of water. The average annual rainfall passing into the soil is 55 centimeters, which gives a dilution of 55/6 = 9. The overall concentration factor for activity in the effluent water from the leachable activity in the soil is 1.1. This gives finally a concentration of activity in the effluent of 2.7E-11, one half of the ALARA guide of 5E-11.

VI. OPERATING CONDITIONS

A conservative calculation indicates that normal operations will be well within ALARA guidelines. The actual beam lost in the scraper can be easily monitored with thermo-luminescent detectors, as in the booster, if that seems desirable. Laboratory effluents are closely monitored, and any increases in activity will be quickly observed.

REFERENCES

1. ORNL-TM-3033, Calculation of the Long-Lived Induced Activity in the Soil Around High-Energy Accelerator Target Areas, T. A. Gabriel, August 12, 1970.

2. AGS FINAL SAFETY ANALYSIS REPORT, D. Beavis, G. Bennett, R. Frankel, E. T. Lessard, M. Plotkin, August 11, 1993.

3. P.J. Gollon, N. Rohrig, M.G. Hauptmann, K. McIntyre, R. Miltenberger, J. Naidu, "Production of Radioactivity in Local Soil at AGS Fast Neutrino Beam", Informal Report BNL 43558.

TABLE 1

Activity due to Individual Nuclides Averaged over The Interval z=1 meter to z=2 meters And Over the Indicated Radial Intervals

Number of 3-GeV Proton-Pb Nucleus Collisions/sec = 10^13/sec
Time of irradiation = 25 years   Time after shutdown = 1 month
From Table III of Reference 1

INNER RADIUS cm.	OUTER RADIUS cm.	MATERIAL	DENSITY grams/cc	ACTIVITY	
				^{3}H Ci/cc	^{22}Na Ci/cc
122	152	CONCRETE	3	1.56E-06	1.49E-06
152	183	SOIL	1.8	2.61E-07	3.56E-07
183	244	SOIL	1.8	8.41E-08	1.30E-07
244	335	SOIL	1.8	1.67E-08	2.77E-08
335	457	SOIL	1.8	1.70E-09	3.32E-09

TABLE 2

Input for Fitting Procedure

MEAN RADIUS cm.	ACTIVITY		ACTIVITY * RADIUS		INTEGRATED DENSITY grams/cm^2
	^{3}H Ci/cc	^{22}Na Ci/cc	^{3}H Ci/cm^2	^{22}Na Ci/cm^2	
137	9.36E-07	8.94E-07	1.28E-04	1.22E-04	45
167.5	2.61E-07	3.56E-07	4.37E-05	5.96E-05	117
213.5	8.41E-08	1.30E-07	1.80E-05	2.78E-05	199.8
289.5	1.67E-08	2.77E-08	4.83E-06	8.02E-06	336.6
396	1.70E-09	3.32E-09	6.73E-07	1.31E-06	528.3

TABLE 3

Concentration of ^{22}Na in Effluent

1	Activity in soil from Graph 3	3.3E-10	Ci/cc
2	Available activity since only 7.5 % of ^{22}Na is leachable	2.5E-11	Ci/cc
3	Fraction of soil that is water	0.1	
4	concentration facter 1 unit vol of water exposed to 10 unit volumes of soil	10	
5	Dilution factor		
	a. Activity is essentially contained in a 1/e thickness of irradiated soil	60	cm
	b. fraction of soil that is water	0.1	
	c. height of water column in soil	6	cm
	d. annual rainfall that percolates down to ground water	55	cm
	e. dilution = 55/6	9	
6	Overal concentration factor of activity from soil to water	1.1	
7	Activity in effluent	2.7E-11	Ci/cc
8	ALARA Guide	5E-11	Ci/cc

Fig. 1 ACTIVITY * RADIUS vs SHIELDING for ^{22}Na

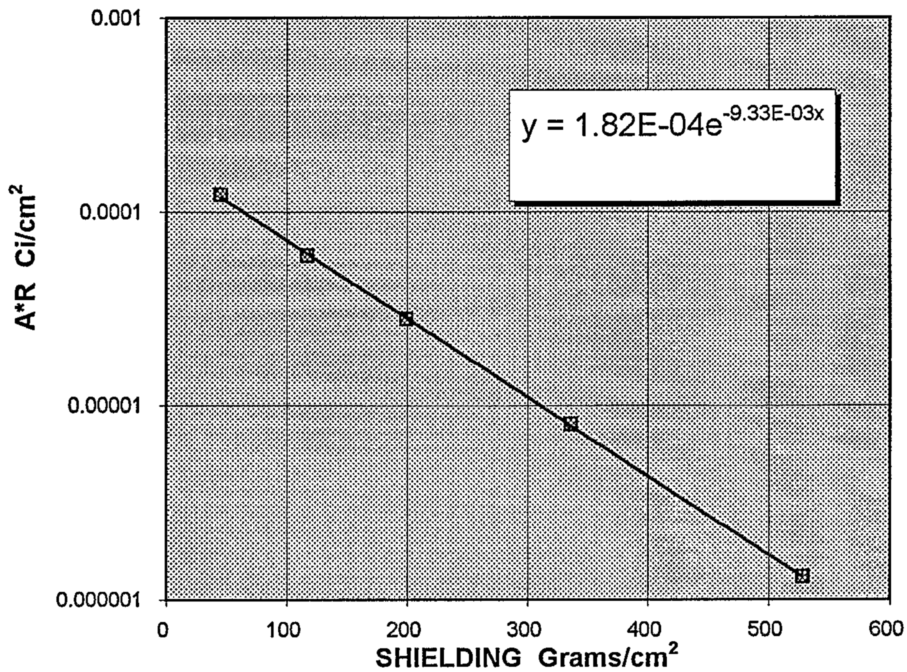


Fig. 2 ACTIVITY * RADIUS vs SHIELDING for ^{3}H

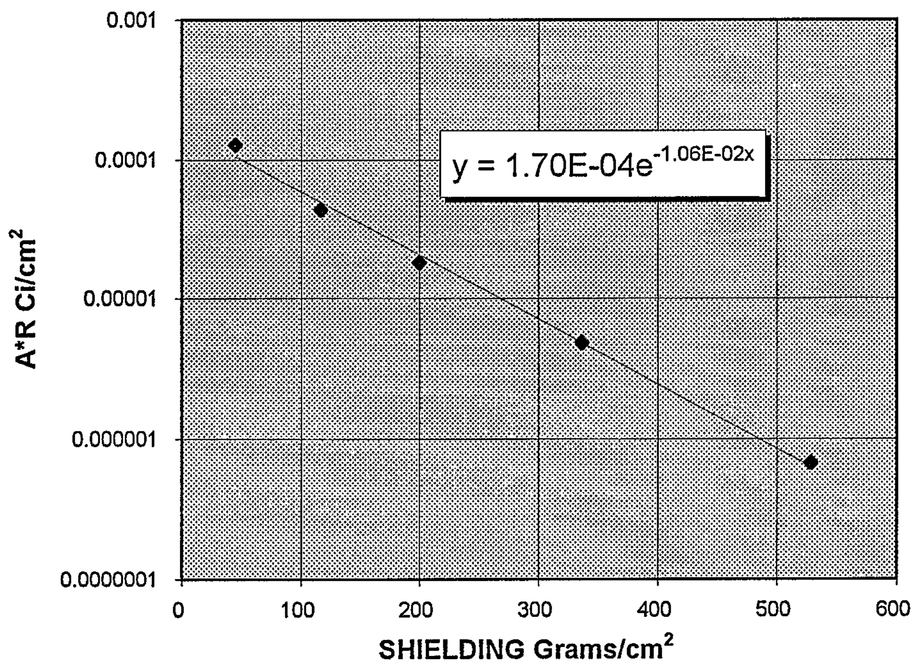
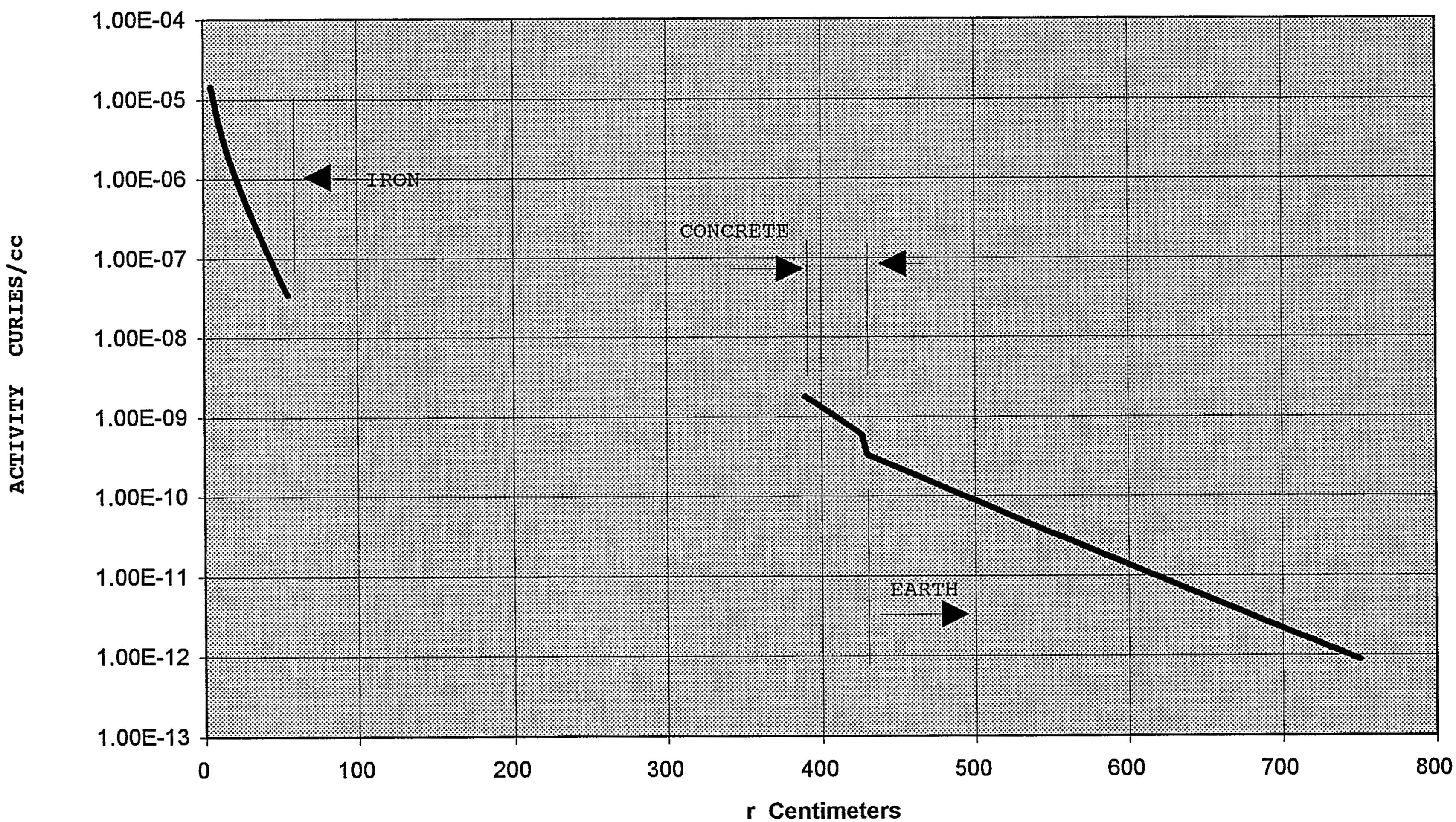


Fig 3 ACTIVITY vs RADIUS

FOR J-10 DUMP WITH 55 CM OF IRON SHIELDING

AT 1995 INTENSITY WITH 5% LOSS AT FULL ENERGY



- 7 -

APPENDIX I

ABSORPTION LENGTHS

FOR K = 0.00933 cm2/gram				
MATERIAL	K(material)	Units	L = 1/K	Units
EARTH	0.0168	cm^{-1}	60	cm
CONCRETE	0.0280	cm^{-1}	36	cm
IRON	0.0728	cm^{-1}	14	cm