national accelerator laboratory

TM-419-A
1100.500

RADIOLOGICAL EXPERIENCE WITH THE FALL 1972 MONOPOLE DUMP

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July 1973

Introduction

During the fall and winter of 1972, a dump was installed in the Neutrino Target Hall to search for magnetic monopoles produced by protons and other particles. The main purpose of the dump was to obtain an early estimate for an upper limit for magnetic monopole production. A secondary goal was to gain experience in handling radioactive materials. Iron is the most desirable material for monopole searches because magnetic monopoles are bound strongly to the magnetic iron. Less desirable, but possible, is the use of aluminum since it is a paramagnetic and still binds poles, although much less strongly. For this exposure an iron dump was chosen consisting of 446 steel, a type of steel frequently used in the manufacture of cutlery that has a saturation magnetization of 12,000 G. Relative to normal magnetic iron, tightly bound magnetic monopoles are easier to extract from 446 steel. The Curie temperature is 610° C. It is desirable to have this temperature as high as possible so that any heating of the dump will not destroy its magnetic properties.

Figure 1 shows a schematic of the dump that was used. The 446 steel is segmented into rectangular blocks, each 1 in. × $1\frac{1}{2}$ in. and about

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0.4 in. thick with a quarter-twenty tapped hole in the center to facilitate remote handling.

In carrying out the secondary purpose of the experiment, a number of properties can be studied. The beam containment within the dump, the gross radioactivity, the lifetime of the activities, and the property of the beam spot on the dump can be measured. For the exposure to protons the dump was mounted on the front end of the so-called auxiliary beam dump of the target train. A one-foot-long aluminum target was used to produce the pion beam which in turn produced the neutrino beam. This target was located about 75 feet upstream of the auxiliary dump; in between was a series of magnets which provided momentum dispersion, thereby separating the proton beam and the pion beam. The geometry is illustrated schematically in Fig. 2. These magnets were tuned so that the proton beam struck the magnetic monopole dump. In addition, particles other than protons impinged on it. The beam position on the dump was monitored via a scintillation screen viewed by a TV camera. The beam spot used on the dump during this period was a minimum of 3 mm $\times$ 3 mm.

Autoradiography

Two techniques were used to determine the position of the beam on the dump after it was removed from nu hall. A sheet of G-10 (an epoxy material) was attached to the front end of the dump. G-10 darkens under a very small exposure of protons. The effect saturates quickly so that a light brown spot is visible even for a very low proton exposure. For this reason G-10 is more likely to show halos than some other techniques. A graphical representation of the spots on the G-10 foil is shown in Fig. 3. A number of different beam centers can be seen which probably resulted from very low intensity beams.

A second technique, the exposure of a polaroid sheet to both the steel blocks and the copper monitor foil placed on the front end of the dump, was also used. Figure 3 also shows the polaroids for the copper foil and the upstream 446 steel slug. The main beam spot is located to the east side of the dump. In addition, the effect of a slight misalignment between the copper foil and the 446 steel is visible. There is some indication that the copper did not completely cover the steel, so that it is possible that a small amount of proton beam was missed by the copper monitor. The beam spot size as shown by the autoradiographs is comparable to the beam spot sizes observed in other measurements in nu hall during this period. This technique provides a very effective tool for monitoring the performance of the dump after it has been removed from the accelerator.

Depth of Dose Curves

Because of the segmentation of the dump, it is possible to observe the radioactive buildup as the beam passes through the dump. Figure 4 illustrates the 300-day half life Mn^{54} activity measured as a function of position through the dump using the Radiation Physics lithium-drifted germanium detector. The bottom curve shows the activity for the inner layer of samples nearest the beam in the dump. The second curve shows results for the outer layer of samples away from the beam. Initially, at the front end of the dump, the outer layer received about one-third the radiation that the lower half, the one closest to the beam, received. By the time the far end of the dump is reached, the ratio is down to something like 2.5 : 1 showing that the nuclear shower is flaring out from the center line of the beam.

Gamma Rays Present in the Dump Material

Both the copper foil and the 446 steel blocks were searched with the lithium-drifted germanium detector. Table I shows the gamma rays that were present. For reference, the estimated chemical composition of the dump is

446 steel composition (handbook values)
- 0.2% C maximum
- 1.5% Mn
- 0.040% P
- 0.030% S
- 1.0% Si
- 23 to 27% Cr
- Others, 0.25% at maximum.

In general, the gammas that were present in the iron were produced either from the iron itself or from the chromium that forms about 27% of the composition by volume. There is some indication of a higher Z impurity in the sample, around 88.

It is interesting to note that some longer half lives, such as Na^{22}, are present but in a relatively small amount. Mn^{54} provides the most practical long-term monitor.

Local Aging Curve

For proper hot handling of the dump it is useful to know the radioactive decay pattern of the sample. Most of the real precautions in this regard are related to shielding so that higher energy gamma rays should be given a heavier weight. The best technique for following the decay history of the dump would have been to take dosimetry readings as soon as the dump was removed from nu hall. With these and a controlled geometry, the radioactive history of the dump could have been followed for some months. For several reasons, this was not done. Initially when the dump was removed from the train, it showed 30 mrad at 1 ft and 600 mrad at the surface for the hottest spot. When the dump was finally removed from nu hall, the hottest block showed 100 mrad on contact. The dump was left in nu hall for some time after it was removed from the train to provide easier handling in removing it from nu hall. For this reason, it was not possible to readily follow the radioactive decay.

Instead, for this set of measurements, the activities found with the Ge-Li crystal have been reconstructed to obtain some idea of both the history and the future behavior of the dump. The three most prominent isotopes have been followed back to a time about one month after the removal of the sample from nu hall. These isotopes are Mn^{54}, Sc^{46}, and V^{48}. Figure 5 illustrates the estimated radioactivity of the dump based on energy release as a function of time. Several experimental activity measurements taken at later times are shown. They fit the projected activity quite well.

Note that the exposure extended over a period of several months. At the time of the monopole extraction run, the radioactivity of the sample was essentially dominated by the Mn^{54} with a 300-day half life. Because of this, it would appear that after perhaps a month of cooling, this would be the most appropriate approximation to the cooling curve for many months. It also shows that after about a month or so of cooling, little is gained in cooling longer. At the same time, the long lifetime of the Mn^{54} is useful from a monitor standpoint.

Proton Exposure

The total number of beam particles incident on the dump was calculated by two different methods. In the first, the copper foil from the front of the dump was counted for Mn^{54} and directly compared in the same geometry to a similar copper foil that had been exposed several months later. The later copper foil proton exposure was well known. The proton exposure had been determined from the Na^{24} activity in the copper itself, and had been measured independently using toroids. Previously, the Na^{24} activity in a similar copper foil had been compared to the Tb^{149} activity in a gold foil. Agreement between these measurements was within the 10% uncertainty of the measurements. The number of protons on the dump was obtained by computing the relative intensities and thicknesses and then folding in a straightforward estimate of the relative date of the two different exposures. This technique gave a total beam particle exposure for the dump of 3×10^{15} particles. In view of the magnetic sweeping arrangement, it is felt that a very large fraction of these were protons. This number is consistent, although somewhat lower than the number estimated upstream using SWIC monitors.

A second technique was used, that is, to assume that the 17 mb cross section for production of Mn^{54} in iron measured at 24 GeV was the same at the 200 to 300 GeV energies used in this exposure. Based on the behavior of production cross sections at lower energies, this would appear to be a fairly good approximation. When this number was folded in and adequate attention was paid to the fraction of iron in the sample, a total exposure of 3×10^{15} protons was obtained. This indicates that it is probably a safe technique for rough experiments such as these to use the direct Mn^{54} activity in the iron dump itself to determine the total exposure. If beam containment is properly handled, accuracies in the neighborhood of 10% can be obtained with this technique.

Future Improvements

A number of aspects of the handling of the dump need better control in the future. For one, it is desirable to monitor the temperature of the dump, particularly as the beam intensity is increased. In order to avoid losing the ferromagnetic property it is mandatory that the temperature be held below the Curie temperature of the iron sample. Monitoring can be accomplished through use of thermistors wired on the face of the dump. Trials on this technique are already underway by R. Stefanski of the Neutrino Section. In addition to this, it is desirable to have long-term measuring devices that keep accurate records of both the energy history of the dump, that is, the incident beam energy and the cycling of the dump with beam as a function of time. It is also important to design the dump in such a way that the beam is not too close to the edge. Aside from aspects of the problem having to do with retaining the magnetic monopoles, it is important that leakage of the beam itself not occur so that the calibration is reasonably accurate. At the same time, of course, it is desirable that monitor foils subtend the same area as the dump itself.

TABLE I

Prominent Gamma-Ray Emitting Isotopes Present in the 446 Sample

Isotope	Energy (keV)	Lifetime (days)	Counts	Counts/ Counts Mn^{54} * (in percent)	Counts/Eff. Normalized to Mn^{54} † (in percent)
Co^{57}	122.0	270	3652	6.8	0.9
Co^{57}	136.1	270	525	1.0	0.1
Cr^{51}	320.2	28	36670	67.9	25
Zr^{88}	392.8	85	1100	2.0	0.9
Be^{7}	477.8	54	3672	6.8	3.8
Co^{58}	810.9	71	1501	2.8	2.6
Mn^{54}	834.9	300	54024	100	100
Co^{56}	846.8	77	4987	9.2	9.3
Sc^{46}	889.3	84	25134	46.5	50
Y^{88}	898.0	107	453	0.8	0.9
V^{48}	944.2	16	1594	3.0	3.4
V^{48}	983.5	16	19034	35.2	42
Co^{56}	1037.7	77	740	1.4	1.7
Sc^{46}	1120.6	84	20715	38.3	52
Co^{56}	1238.4	77	2442	4.5	6.3
Na^{22}	1274.6	950	609	1.1	1.7
V^{48}	1312.1	16	14162	26.2	42

*The next to the last column is the ratio of counts for the particular isotope divided by Mn^{54} counts expressed in percent.

†The last column is the relative percent yield, without correction for self-absorption, of the gamma ray compared to Mn^{54} about two months after a sporatic irradiation over a period of two months. The gamma ray counts for both the isotope and Mn^{54} have been divided by the appropriate detector efficiency.

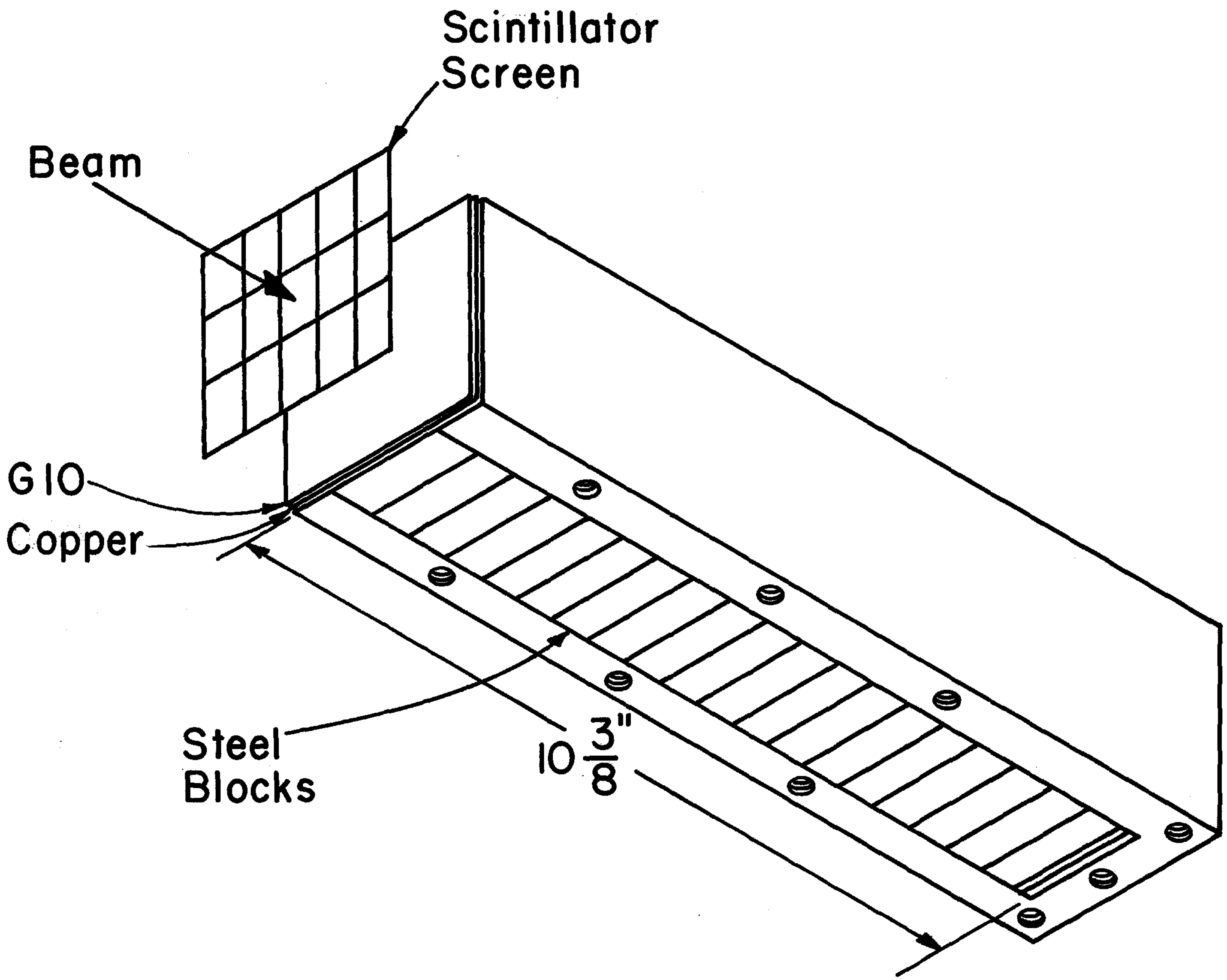

Fig. 1. Detail of monopole dump.

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Figure 2 – Schematic of Dump Location in Nu-Hall

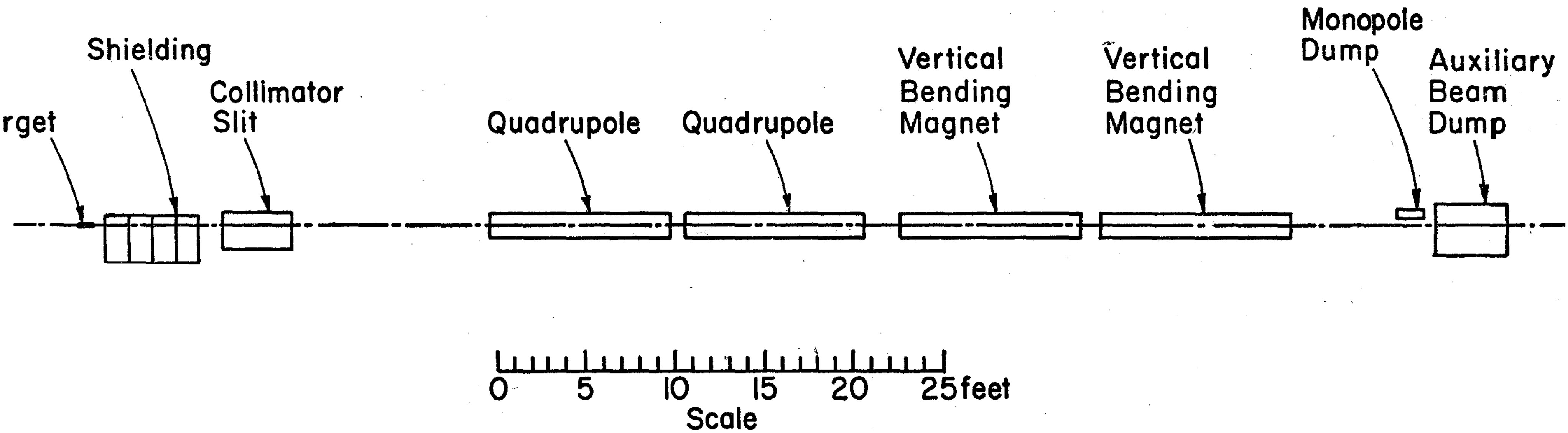
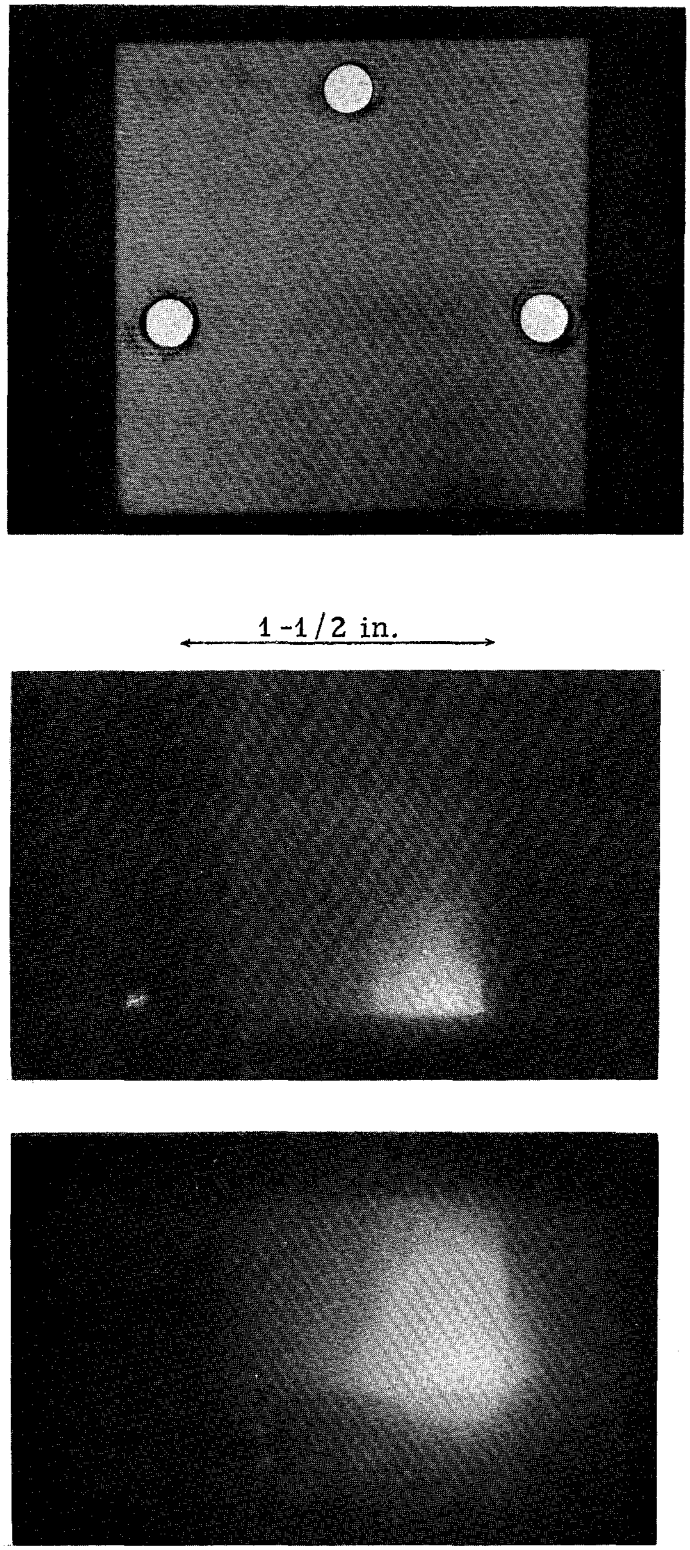


Fig. 2. Schematic of dump location in Nu-Hall.



G-10 Epoxy

Copper Foil

Iron Block

Fig. 3. Beam at dump (pion beam is below spot on dump).

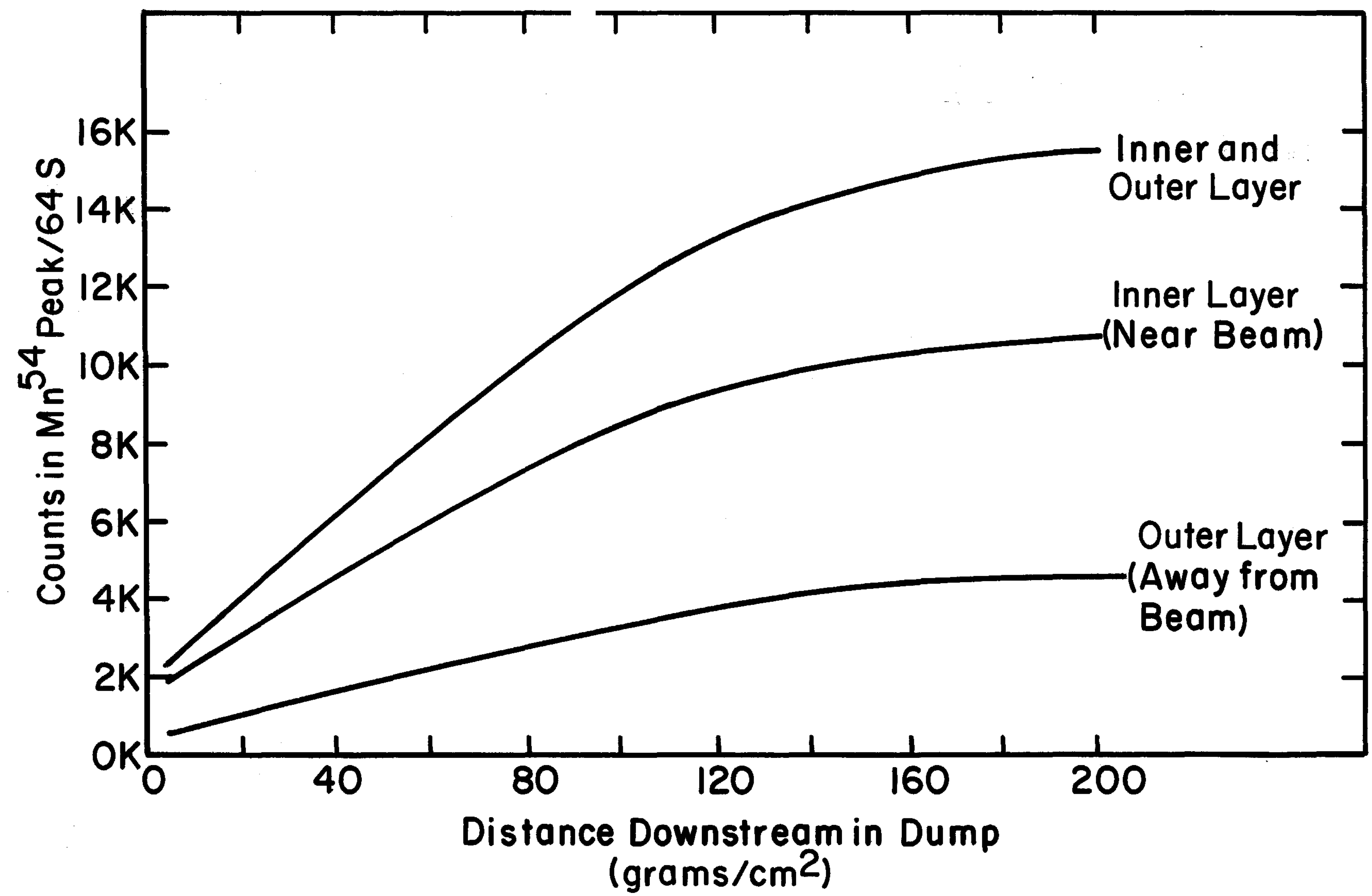


Fig. 4. Radioactivity in beam direction (446 steel).

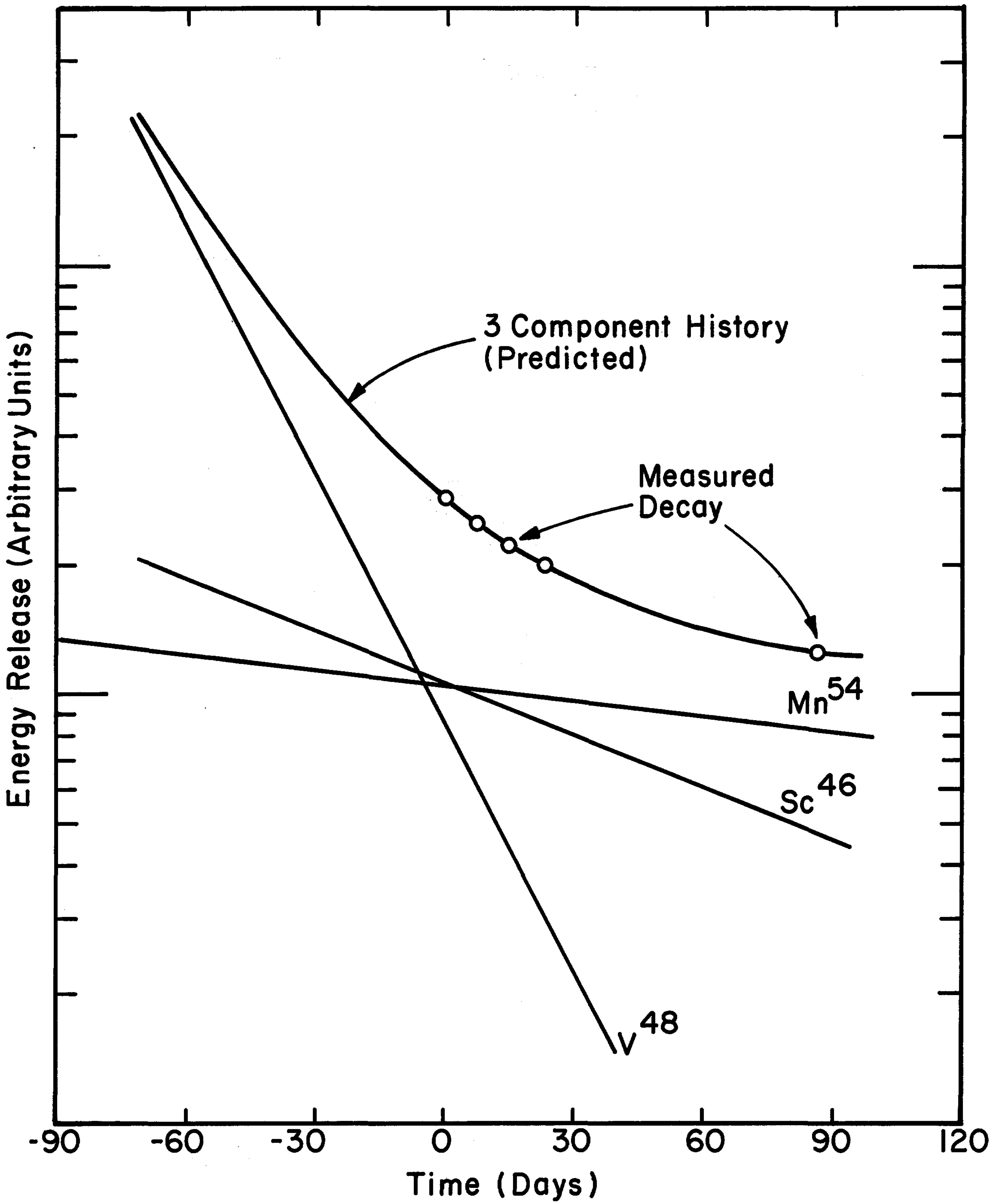


Fig. 5. Estimated radioactivity of dump as a function of time.