Fermilab Proposal No. 631

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A Proposal to Measure Nuclear Calibration Cross Sections for Protons between 100 and 1000 GeV

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ABSTRACT

We propose to measure the cross sections for the production of ^{24}Na and other high-threshold radionuclides in copper by protons in the energy range between 100 and 1000 GeV. We wish to determine these cross sections to three per cent accuracy by comparison with the results from a toroid.

Table of Contents

Introduction

Use of ^{24}Na production in copper to determine the number of protons in an extracted proton beam from a high energy accelerator has several advantages over methods previously used:

1. The effective threshold of around 400 MeV makes the result less sensitive to beam quality than most other reactions, e.g., ^{24}Na production in aluminum.[1]
2. The determination is less sensitive to thickness corrections since gamma rays are counted rather than alpha particles. Formerly, alpha particles were counted from the production of ^{149}Tb in gold.[2]
3. The proximity of the gamma-ray energy (1.369 MeV) to that of ^{60}Co (1.332 MeV) makes accurate determination of detector efficiency possible.
4. Measurements to date indicate that the cross section is essentially independent of energy from 10 GeV to 400 GeV. These results are given in Table 1.

The development of the high resolution Ge(Li) gamma-ray detector made it easy to separate the ^{24}Na 1.369 MeV gamma ray from the multitude of others resulting from the spallation of copper. Such a separation required peak-stripping techniques using the NaI (Tℓ) detectors available earlier. That precluded the routine use of the technique for beam intensity measurements.

Accurate determination of the number of protons incident on a target is a requirement for almost every experiment at a high energy accelerator. See Appendix A.

TABLE 1. Cross Section Measurements

Energy (GeV)	Date	Location	Cross Section ^{24}Na from Cu (mb)*	Reference
11.5	1975	ANL	4.0	3
30	1976	BNL	3.6	4
195	1979	CERN	3.8	5
200	1979	Fermilab	4.0	6
400	1977	Fermilab	3.8	6
400	1979	CERN	4.0	5

*Uncertainties approximately five to ten per cent.

Toroids can be used when the current is high enough (typically 10^{11} protons or more in one millisecond). Individual protons can be counted accurately up to about 10^6 per second. Outside these ranges foil activation is a valuable alternative since it can be used for calibrating instruments such as secondary emission chambers and ion chambers which monitor the number of protons. These instruments cannot be calibrated absolutely by passing a current through them as a toroid can.

The secondary emission chamber has a temporal response problem. The work function of the foil surfaces is very sensitive to many outside influences. Although the chamber is evacuated, residual gases react with the surfaces especially at locations heated and/or damaged by interactions of protons in the beam. Thus, a carefully calibrated secondary emission chamber can change its response in an unpredictable manner.

The ion chamber suffers primarily from recombination problems. Too high an ion density can result in a lower response because the ions recombine in the gas rather than traveling to the collection plates. The ionization process also exhibits relativistic effects which must be taken into account. This relativistic rise with momentum can require corrections as large as ten per cent.

There have been a few cross section measurements made at energies above 30 GeV in copper by comparison with a toroid (see Table 1) or by counting the number of protons[7]; however, there have been no systematic studies which will eliminate uncertainties such as effects due to thickness of foil and beam pipe end windows. This proposal includes measurements in vacuum with several different foil and window thickness to obtain this information. There have been no measurements of cross sections in copper above 400 GeV. We wish to extend these measurements to 800 or 1000 GeV. We are confident that we can reduce the uncertainties in the cross section measurements to less than five per cent and will endeavor to reach an accuracy of three per cent.

II. Importance of Irradiation Location

As part of the upgrade of Fermilab to Tevatron energies, a new abort dump will be built near CO in the Main Ring. This abort dump will be outside the existing tunnel and separate beam pipes will be run to it. This is in contrast with the existing beam abort system which is in the Main Ring Tunnel at DO. Thus, there will be a unique opportunity to place foils in a region which will have very little scattered radiation and can receive energies up to the maximum being accelerated. Since the energy of the protons can be changed by changing the time during the cycle at which the beam is aborted, the energy dependence can be accurately measured. Irradiating two foils in succession at different energies without changing any other parameters is a powerful technique for determining the energy dependence. Also, one should be able to obtain protons of about 8 GeV, the energy of protons injected from the Booster accelerator, for a low energy check. The result of the measurements using the aborted beam will be a curve (probably a straight line at energies above 100 GeV) from which one will be able to determine the cross section at any energy from 8 GeV to about 1000 GeV.

III. Cross Calibration

We also propose to use this opportunity to cross calibrate the proton beams from Fermilab, CERN, and BNL. Since the radionuclides produced in copper have sufficiently long half-lives, foils from these irradiations can be taken elsewhere for counting on other systems. We propose to do such counting of Fermilab foils at CERN and Brookhaven. Following the completion of ISABELLE at Brookhaven, results of foil activation measurements there with protons of about 400 GeV can be compared with Fermilab foil results. Systematic differences between different counting systems will thus be eliminated, leading to a better cross calibration between the high energy physics laboratories having proton beams with energies above 100 GeV and easier comparison of results from such laboratories.

IV. Requirements

This experiment is most logically done as a series of irradiations in conjunction with accelerator studies. The following apparatus is needed:

1. Two toroids with remote electronics to determine the number of protons incident on the foils.
2. Remotely controlled motion of one toroid to study effects of secondary particles on the toroid. This toroid should be capable of movement in and out of the beam.
3. A vacuum chamber for the toroids and foils to eliminate secondaries produced in vacuum windows. The vacuum chamber needs to be placed in a low magnetic field region (less than about ten Gauss) for proper operation of the toroids.
4. A remotely controlled sample changer to insert and remove foils to eliminate the need for controlled accesses.

Each foil packet needs to be outside the tunnel except while it is being irradiated. We propose to accomplish this by making a vertical penetration of the tunnel and introducing the packet through a shaft from the top of the berm.

V. Experimental Plan

Much of the initial set-up and study of effects of secondaries can be done in a parasitic mode. We would check out our toroids during studies of the abort system or Main Ring studies requiring the abort system. Since such parasitic time (about 30 hours) should be readily available, the total beam time commitment for investigation of effects of secondaries would be less than one hour. This beam time would be used for irradiation of titanium and copper foil packets and for putting thick foils in the aborted beam to purposely produce secondaries in the toroids.

We plan to make approximately five irradiations at each energy in the study of the energy dependence. Since we expect the cross section to be relatively independent of energy, only about five different energies should span the energy range. We would concentrate on one energy, 400 GeV, for the intercomparison and most accurate determination of the cross section.

The study of the energy dependence would be done in two phases:

1. From 8 GeV to 400 GeV using the Main Ring beam, and
2. Comparison of 400 GeV and one higher energy (probably 800 GeV) using the Tevatron beam.

Since each irradiation will require about 4×10^{14} protons, the total beam time required will be about six hours, assuming a 60 second cycle for the Tevatron and an eight second cycle for the Main Ring at about 2×10^{13} protons per pulse. We anticipate that only about four foil packets will be irradiated on any given day; therefore, elimination of controlled access is an important consideration.

VI. Personnel Commitments and Timing

We anticipate that the first phase of the experiment (using the Main Ring proton beam) would take approximately one calendar year to complete. The second phase (using the Tevatron beam) would take about three months and would not be done until the beam becomes available (1982-3). The total collaborator commitment would be about two man years with more than half of that being furnished by Fermilab.

This experiment should be designed, installed, and checked out in conjunction with the new abort system at CO. This latter is scheduled for installation during the summer. Thus, we anticipate that the first irradiation would occur in the fall of 1980 and would like to receive approval as soon as possible.

VII. REFERENCES

1. Nuclear Data Tables A7 #1 and #2 (1969).

2. E. P. Steinberg et al., Nucl. Phys. A113, 265 (1968).

3. S. I. Baker, Fermilab Report FN-276 (1975).

4. J. B. Cumming et al., Phys. Rev. C14, 1554 (1976).

5. A. Chapman - Hatchett et al., CERN Report SPS/ABT/Int. 79-1.

6. S. I. Baker, unpublished comparisons to toroid in Encl. 99 at Fermilab March 1977 and December 1979.

7. S. B. Kaufman et al., Phys. Rev. C13, 253 (1976).

Appendix A. Fermilab Experiments Requiring Special Beam Intensity Measurements

The following experiments performed at Fermilab have required special foil activation measurements to determine the number of protons incident on their targets.

Experiment Number	Spokesperson and/or Person Requesting the Irradiation(s)
14	P. Franzini
21A	F. Sciulli, O. Fackler
26	L. Hand, K.W. Chen, S. Loken
70	L. Lederman
81A	S. Kaufman
95A	B. Cox
100	J. Cronin
108	M. Awschalom
177A	C. Hojvat
221	P. Francini, S. Childress
258	H. Frisch
284	J. Walker, R. Shafer
288	L. Lederman, J. Appel
300/325	J. Cronin
310	R. Stefanski
356	O. Fackler
439	J. Rutherfoord
537	B. Cox
613	S. Childress
616	O. Fackler, T. Kondo

ADDENDUM TO PROPOSAL NO. 631

In view of the two-year period now anticipated before the new abort dump will receive protons, consideration should be given to doing all but the energy dependence in the Neutrino Area. Because the beam spot size will be small (initially about 0.5 mm by 1.2 mm) and single-turn extraction will be used in aborting the beam into the abort dump, there is the potential for evaporating the foil material. We propose to investigate this potential in the Neutrino Area by comparing millisecond extraction with single-turn extraction. Single-turn extraction is available, has been used in the past in the Neutrino Area, and the periods of single-turn extraction required for activating the foils are very short. Thus, we believe single-turn extraction could be accommodated without disrupting the program.

The burden of performing portions of the experiment at different locations has prompted us to seek additional aid. We wish to submit the name of A. Soukas of Brookhaven National Laboratory as a collaborator on this experiment. He will supply needed expertise in the areas of instrumentation and chamber design.

To give a better understanding of sources of error in the measurement, we submit the following:

Source	Percentage Uncertainty
Uncertainty in detector efficiency	1.4
Uncertainty in foil thickness	approx. 1
Effect of beam spot size (attached curve, Fig. 1)	less than 1 for typical spot sizes
Effect of cascade build-up	less than 1
Toroid absolute calibration	less than 1
Effect of halo on toroid measurement	large*
Effect of halo on foil measurement	proportional to amount of halo
Statistical uncertainty (typical Ge(Li) spectrum, Fig. 2)	less than 1
Systematic uncertainties not mentioned above	less than 3, can be reduced

*Secondaries going through the material of the toroid or the electronics can produce changes in signal much larger than those which result from the same number going through the center of the toroid.

FIGURE 1. EFFECT OF OFF-AXIS SOURCE ON EFFICIENCY

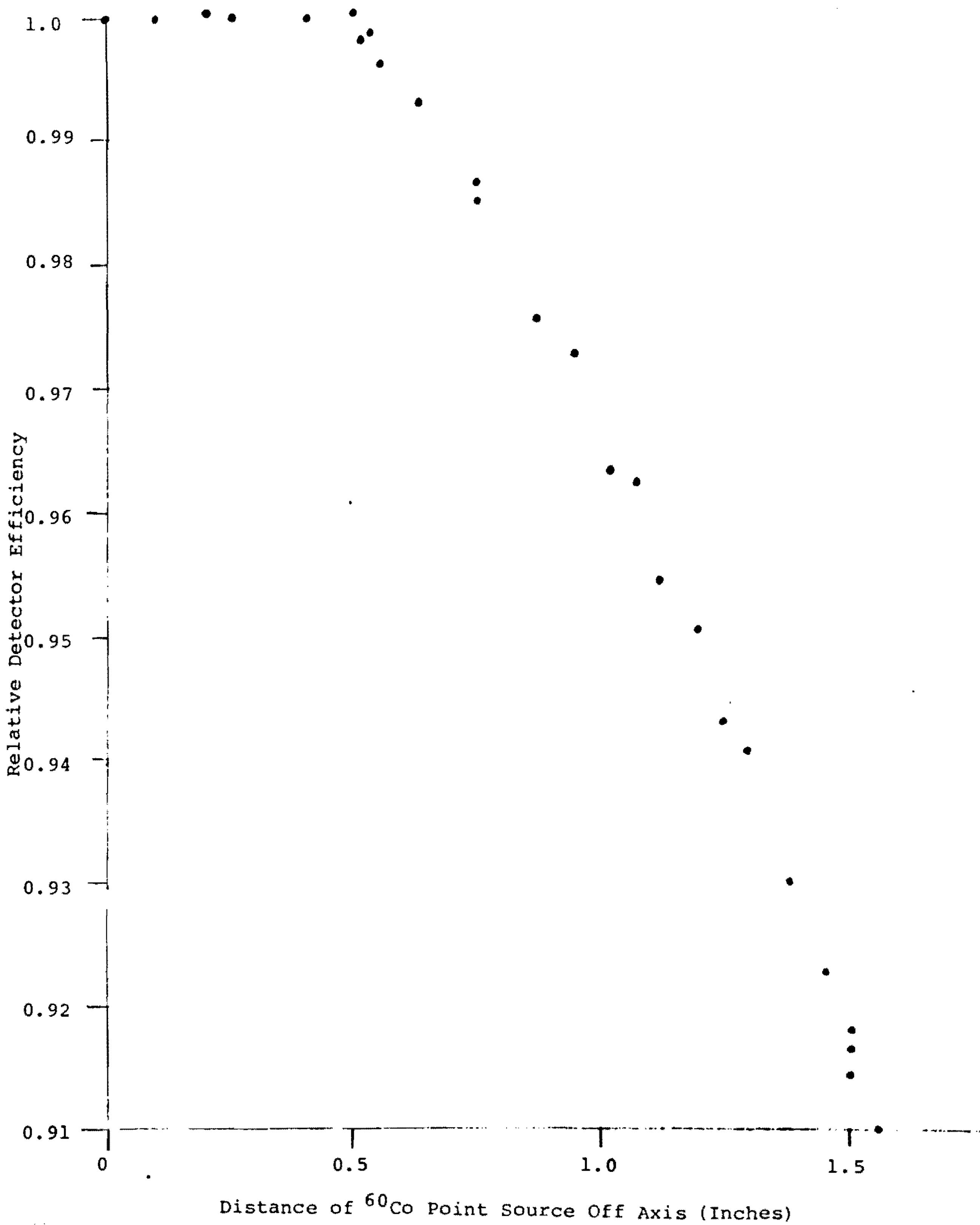

Figure 2. Ge(Li) Detector Gamma-Ray Spectrum for Copper Foil