

BEAM INTENSITY MEASUREMENTS USING COPPER FOILS

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ABSTRACT

Discrepancies observed between the beam intensity measurements based on  $^{24}\text{Na}$  production in  $^{63-65}\text{Cu}$  and other techniques have been traced to the published value of that cross section. Foil irradiations at Argonne and Brookhaven Laboratories yielded a cross section of  $4.0 \pm 0.3$  mb. This value is not in agreement with the  $3.5 \pm 0.3$  mb cross section found in the literature.



## INTRODUCTION

Copper foils are used for calibration of secondary emission monitors (SEM's) measuring proton beam intensities at Fermilab. A large number of radionuclides are produced by the proton bombardment of copper; however,  $^{24}\text{Na}$  was chosen for the calibration because the effective threshold energy for its production is high, about 400 MeV; the 15 hour half-life is convenient for exposures and counting, and the emitted gamma rays are easily detected. The production of  $^{149}\text{Tb}$  in  $^{197}\text{Au}$ , another reaction with high threshold, has not been used at Fermilab because its shorter half-life (four hours) and thickness corrections or chemical separations required for counting the alpha particles emitted were less convenient. The well studied production of  $^{24}\text{Na}$  in  $^{27}\text{Al}$  is not used because it has a lower effective threshold, 30 MeV, and also has a higher cross section for production by neutrons of about 10 MeV which often are present as the result of interactions of protons with beam handling components.

Up to the present time the cross sections<sup>1,2</sup> for  $^{24}\text{Na}$  production in  $^{63-65}\text{Cu}$  (natural copper) measured at about 30 GeV have been used at Fermilab because absolute cross section measurements at higher energies were not available.\* From the constancy of the cross sections<sup>1</sup> between 5 and 30 GeV, it was expected that the cross sections at 200-500 GeV would not be grossly different from these values.

\* A preliminary result ( $24.6 \pm 1.6$  mb) is now available<sup>3</sup> for the production of  $^{11}\text{C}$  in  $^{12}\text{C}$  from measurements made at 300 GeV. Based on that measurement and relative cross section measurements made by the Fermilab Radiation Physics Group, the cross section at 300 GeV for  $^{24}\text{Na}$  production from  $^{63-65}\text{Cu}$  is also approximately 4.0 mb.

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In the course of making SEM calibrations, evidence began to accumulate which suggested that the cross section being used was in error. Discrepancies of about 20 per cent were observed between the number of protons passing through the SEM as determined from  $^{18}\text{F}$  production from  $^{27}\text{Al}$  and as determined from  $^{24}\text{Na}$  production in  $^{63-65}\text{Cu}$ , the number determined from copper being higher. In addition, a special experiment conducted at a point just beyond the beam extraction elements at Fermilab also yielded a higher result from copper. In this experiment toroidal current transformers measured the circulating beam in the main accelerator to an accuracy of better than  $\pm 5\%$ , and a technique developed by F. Hornstra<sup>4</sup> allowed us to calculate the extraction efficiency with an accuracy of better than  $\pm 1\%$ . Hence, a well known proton flux traversed the copper foils. This proton flux was 10% lower than the proton flux calculated using the published value<sup>1,2</sup> of the cross section for the  $^{63-65}\text{Cu} (p,x) ^{24}\text{Na}$  reaction.

To see if the published value for the cross section for  $^{24}\text{Na}$  production from  $^{63-65}\text{Cu}$  could be the main source of the discrepancy, irradiations of copper foils were made at the Argonne National Laboratory ZGS and Brookhaven National Laboratory AGS accelerators.

#### IRRADIATIONS AT ANL

In December 1974 foil exposures were made in the internal beam of the ANL zero gradient synchrotron using a flipper to position the foils following proton acceleration to 11.5 GeV. The foil stack is shown in Fig. 1. The effective number of protons traversing the foil was determined by the ANL Nuclear Chemistry Group under the direction of E. Steinberg. The  $^{24}\text{Na}$  activity was counted in one of the aluminum foils using a

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beta-gamma coincidence technique. The flipper was inadvertently stopped in the beam position for two or three pulses at the end of the scheduled 15 pulse irradiation. Also, some difficulty was experienced in cutting the foils for the first exposure. Hence, the exposure was repeated. All of the cross sections ( $^{18}\text{F}$  and  $^{24}\text{Na}$  from  $^{27}\text{Al}$ ,  $^{24}\text{Na}$  and  $^{52}\text{Mn}$  from  $^{63-65}\text{Cu}$ ) determined from the two exposures agreed to within 7%, with the first result giving a higher cross section for  $^{24}\text{Na}$  from  $^{63-65}\text{Cu}$  than the second. The results for the second irradiation are given in Table 1.

Activities in the second aluminum foil and in the copper foil were measured using the Ge(Li) detectors in the Fermilab Nuclear Counting Laboratory. Production cross sections for  $^{18}\text{F}$  from  $^{27}\text{Al}$  and  $^{24}\text{Na}$  from  $^{63-65}\text{Cu}$  were determined using the effective number of protons as provided by the  $^{24}\text{Na}$  activity in aluminum mentioned above. Thus, the cross sections are based on the  $^{27}\text{Al}(p,3pn)^{24}\text{Na}$  cross section. The value used at 11.5 GeV was  $8.6 \pm 0.6$  mb based on measurements of 8.6 mb made at both 10 and 28 GeV.<sup>5</sup> A 4% correction was made by the ANL Nuclear Chemistry Group for the contribution from secondary particle interactions.<sup>6</sup>

The  $^{24}\text{Na}$  activity in aluminum was counted at Fermilab for a foil from the second irradiation to compare the determination of detector efficiency at Fermilab with that at ANL. The cross section obtained was 1% lower at Fermilab which was within the uncertainty in determining the Ge(Li) detector efficiency based on measurements with National Bureau of Standards calibrated gamma sources.

The result in Table 1 for  $^{18}\text{F}$  production from  $^{27}\text{Al}$  is in good agreement with the adopted cross section at 10 GeV.<sup>5</sup> The 4.0 mb cross section for  $^{24}\text{Na}$  production from  $^{63-65}\text{Cu}$  is definitely higher than that found by Hudis *et al.*<sup>1</sup> at 10 GeV (approximately 3.4 mb) but is in good agreement with Barr's

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result of 4.0 mb as corrected by Hudis et al.<sup>1</sup>. It should be pointed out, however, that the errors overlap (one standard deviation) if the systematic errors of about 5% are included in our measurements.

#### IRRADIATION AT BNL

The foil irradiation at BNL (April 1975) was made in an external beam line and the number of protons,  $(4.01 \pm 0.04) \times 10^{14}$ , passing through the stack was determined using a toroid as a current transformer. The current transformer was developed at BNL with electronics designed by J. Guthy. The stack of foils used contained only copper (Fig. 2) since the time required to get the foils to Fermilab made counting of two hour half-life  $^{18}\text{F}$  produced in aluminum impractical.

The two copper foils counted gave essentially the same results: 4.0 mb for  $^{24}\text{Na}$  production and 5.2 mb for  $^{52}\text{Mn}$  production with a statistical uncertainty of approximately 2% and a systematic error of 5% for each. Hence, the same 4.0 mb cross section was obtained at 11.5 and 28 GeV for  $^{24}\text{Na}$  production in copper. The  $^{52}\text{Mn}$  cross section shows a small decrease between 11.5 GeV and 28 GeV. Assuming the  $^{24}\text{Na}$  cross section remains at 4.0 mb for 300 GeV protons,\* the  $^{52}\text{Mn}$  cross section also shows a small decrease (about five per cent to 4.9 mb) between 28 GeV and 300 GeV from results obtained at Fermilab.

#### CONCLUSION

Most of the discrepancy observed between determinations based on  $^{24}\text{Na}$  production in copper and other techniques used

\* Preliminary results of measurements at 300 GeV support this assumption.

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in SEM calibrations at Fermilab will disappear if the 4.0 mb cross section for  $^{24}\text{Na}$  production is used rather than the 3.5 mb cross section reported by Hudis et al.

#### ACKNOWLEDGEMENTS

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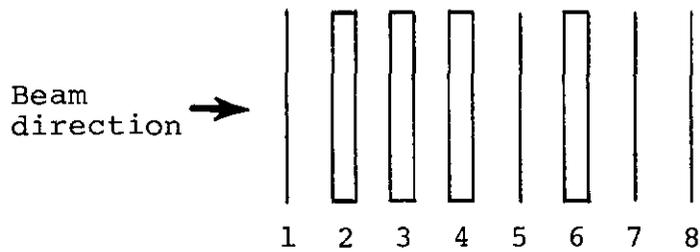
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Table 1. Results of 11.5 GeV Irradiation

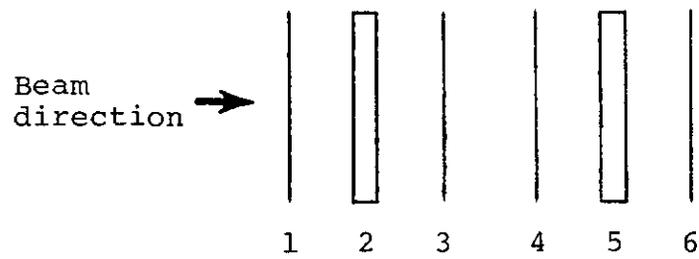
Foil	Radionuclide	Cross Section Determined* (mb)
Aluminum	$^{18}\text{F}$	$6.3 \pm 0.4$
Aluminum	$^{24}\text{Na}$	$8.5 \pm 0.6$
Copper	$^{24}\text{Na}$	$4.0 \pm 0.3$
Copper	$^{52}\text{Mn}$	$5.6 \pm 0.4$

\* The statistical uncertainty was about two per cent.  
The remainder was systematic error.



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|---------|---|
| 1, 4, 8 | Aluminum Cover Foils                    |
| 5, 7    | Copper Cover Foils                      |
| 2, 3    | Aluminum Counting Foils 0.0027 cm thick |
| 6       | Copper Counting Foil 0.0035 cm thick    |

Figure 1. Stack irradiated at Argonne National Laboratory



1, 3, 4, 6      Copper Cover Foils  
2, 5            Copper Counting Foils 0.013 cm thick

Figure 2. Stack irradiated at Brookhaven National Laboratory