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FIRST ON-LINE RESULTS FOR As AND F BEAMS FROM HRIBF TARGET / ION SOURCES

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Abstract: The first on-line tests of the ion sources to provide radioactive ion beams of ^{69,70}As and ^{17,18}F for the Holifield Radioactive Ion Beam Facility have been performed using the UNISOR facility at HRIBF. For ^{70}As the measured efficiency is 0.8± 0.3% with a hold-up time of 3.6 ± 0.3 hours as measured with ^{72}As at a target temperature of 1270°C. For ^{17}F the efficiency for $Al^{17}F$ is 0.0024 ± 0.0008% with a hold-up time of 16.4 ± 0.8 m as measured with $Al^{18}F$ at a target temperature of 1470°C.

DISCLAIMER

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1. Introduction

The recently completed Holifield Radioactive Ion Beam Facility (HRIBF) is designed to provide energetic radioactive ion beams for nuclear physics and nuclear astrophysics research. To produce these beams, light ions from the K = 100 Oak Ridge Isochronous Cyclotron (ORIC) will impact a thick target in the ion source of an isotope separator. The extracted radioactive ions after mass analysis and charge exchange are then injected into the 25-MV tandem accelerator. One of the most challenging aspects of this project is the performance of the target/ion source of the isotope separator. This paper presents results of on-line tests of the initial version of the ion source used to produce As beams. Also, preliminary results for F from a similar source are described.

2. Experimental

The UNISOR separator[1] on-line to the Holifield tandem accelerator provides the capability[2] to investigate target/ion source performance. Low intensity beams of protons or deuterons of energy up to 40 MeV and intensity up to 24 nA from the tandem accelerator produce the

desired radioisotopes directly in the target/ion source under investigation. The mass separated ions are counted using traditional on-line nuclear spectroscopy techniques with a moving tape system, gamma ray detector and spectrum multiscaling techniques. Alternatively, in experiments prior to those reported here, heavy ion implantation experiments similar to those of Kirchner[3] were used to measure release times and efficiencies[2] of various beam/target combinations in preparation for designing and constructing the target/ion source used here.

3. Target/Ion Source

The target/ion source used in these studies is modified from the general design[4] for the HRIBF facility. Figure 1 shows the ion source as used in these experiments. The modifications were made for the specific target (liquid germanium) and ion species (As) being developed for the initial HRIBF beam. The target heater was simplified to a single current pass with heat shield because it was assumed that liquid germanium must be operated below approximately 1100 °C to maintain an ion source pressure below 10^{-4} torr. The cathode connection was moved from approximately midway along the cathode transfer tube to the rear-most point. This ensures that the entire transfer line will be at the highest possible temperature in order to reduce the sticking time[5] of As on the tantalum surface. Several layers of 0.001-inch-thick tantalum (not shown) around the transfer line provide additional heat shielding. A carbon target holder is used since tantalum reacts strongly with germanium. The germanium target is 4 mm thick by 9 mm diameter so that the 40 MeV protons are stopped in the target. The entrance window is 1 mm thick carbon.

Several copies of the target/ion source have been constructed and run off line to determine typical operating parameters. The single current pass target heater can provide a wide range of

target temperatures starting at 900°C with the heater current off and has operated reliably at 1570 °C with a heater current of 480 amps. Moving the cathode connection to the rear of the transfer tube enables the entire transfer line to be operated at temperatures in excess of 1700 °C, as measured at the coldest point next to the cathode current connection, with a current of approximately 360 amps. The other operational parameter which is important for the germanium target is the target temperature without heater current. This temperature is approximately 900 °C with cathode and anode at operational conditions. Typical ion source efficiency for Xe is 10-15% with cathode current of 360 amps and anode current of 200 mA at 150 volts. For on-line experiments the Xe gas inlet is restricted to 0.3 mm in order to reduce the flow of reaction products into the gas line. With this arrangement the on-line Xe efficiency is reduced to 3%.

4. On-line As Experiments

The performance of the ion source for the production of As beams was tested using (p,n) and (p,2n) reactions on a natural 99.999% pure germanium target mounted in the ion source. The data was obtained by bombarding the target/ion source continuously starting at T = 0. Activity deposited in the tape transport system for 10 minutes was then moved to the detector station and counted for 8 minutes. The count rates shown in Fig. 2 are net counts in the respective transitions. These data are used to determine the absolute efficiency for the target/ion source. These data clearly show a hold-up time in the target/ion source and an improvement in yield as the target temperature is increased. At 1300 °C we measured the efficiency for ^{70}As to be 0.8±0.3% and for ^{69}As to be 0.5±0.2% based on production rates from experimental data[7].

Since the growth curve seems to be dominated by the half life of the respective isotopes, the hold-up time as implied from Fig. 2 must be longer than the half life of either ^{69}As or ^{70}As. In order to measure the hold-up time in the target/ion source it was necessary to use an isotope with longer half life than either ^{69}As or ^{70}As. After proton irradiation for several hours enough ^{72}As ($t_{1/2}$ = 26.0 hr) activity is built up in the target to enable such a measurement. In this case the beam is turned off at T = 0 and similar counting as above is done. Fig 3 shows the target/ion source yield as a function of time. Since the radioactive half life in this case (26.0 hr) is much larger than the apparent hold-up time, we say that the hold-up time is 3.6±0.3 hours at 1270 °C.

Target temperature is an important parameter for any target/ion source. In the case of germanium it was expected that since its vapor pressure is 10^{-4} torr at 1100 °C this would be the approximate maximum operating temperature for the target. Figure 4 shows that the target can be operated at much higher temperatures as measured by As yield with no loss of Xe efficiency. These data are corrected for radioactive decay, detector efficiency and branching ratio and normalized to 1 μA of protons.

5. On-line F Experiments

The performance of a similar ion source for the production of ^{17,18}F was also tested in preliminary experiments. The only changes in the target/ion source from that described above is in the target holder and target material. The target material is 3-μm natural Al_2O_3 fibers[6] bound with SiO_2 and the target holder is made of tantalum and welded to the transfer tube.

The reactions used were: $^{16}O(d,n)^{17}F$ ($t_{1/2}$ = 64.5 s) and $^{18}O(p,n)^{18}F$ ($t_{1/2}$ = 110 m). Because of the extreme reactivity of atomic fluorine, it is likely that the fluorine isotopes are transported in molecular form. Approximately 88% of the fluorine is observed at mass 44 (45) corresponding to $Al^{17}F$ ($Al^{18}F$). This is based on measuring the radioactivity at other masses which could correspond to the following molecules (%yield): F(3), HF (2), AlF (88), SiF (7). In addition the following molecules (mass positions) had negligible activity: BeF, NaF, BeF_2 , KF, and AlOF. At a target temperature of 1470 °C the efficiency for $Al^{17}F$ was 0.0024 ± 0.0008%, and the efficiency for $Al^{18}F$ was 0.06 ± 0.02%. The production yields were calculated from the measured cross sections[8] and tabulated stopping powers[9]. The uncertainty in the efficiency is primarily due to the estimated uncertainty in the proton beam current on the target. The hold-up time was also measured at 1470°C using the longer lived ^{18}F isotope. The results of this measurement are shown in Fig. 5. By fitting the activity with an exponential, the hold-up time was determined to be 16.4 ± 0.8 m.

Acknowledgments

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Figure Captions

Fig. 1. Axial cut of the HRIBF liquid germanium-target ion source. Part numbers and construction material are indicated: 1) Cathode current lead (Ta), 2) Gas (Xe) transfer line (Ta), 3) transfer line (Ta), 4) Head Flange (C), 5) Outer tube (C), 6) Heat shields (Mo or Ta), 7) Cathode support nut (Mo), 8) Anode support tube (Ta), 9) Cathode (Ta), 10)Anode tube (Ta), 11) End flange (Mo), 12) Anode heat shields (Mo), 13) Anode support assembly (Ta,BeO,Mo), 14) Anode wire (Mo), 15) Target holder (C for Ge, Ta for Al_2O_3), 16) Heater (Ta), 17) Heater heat shield (Ta).

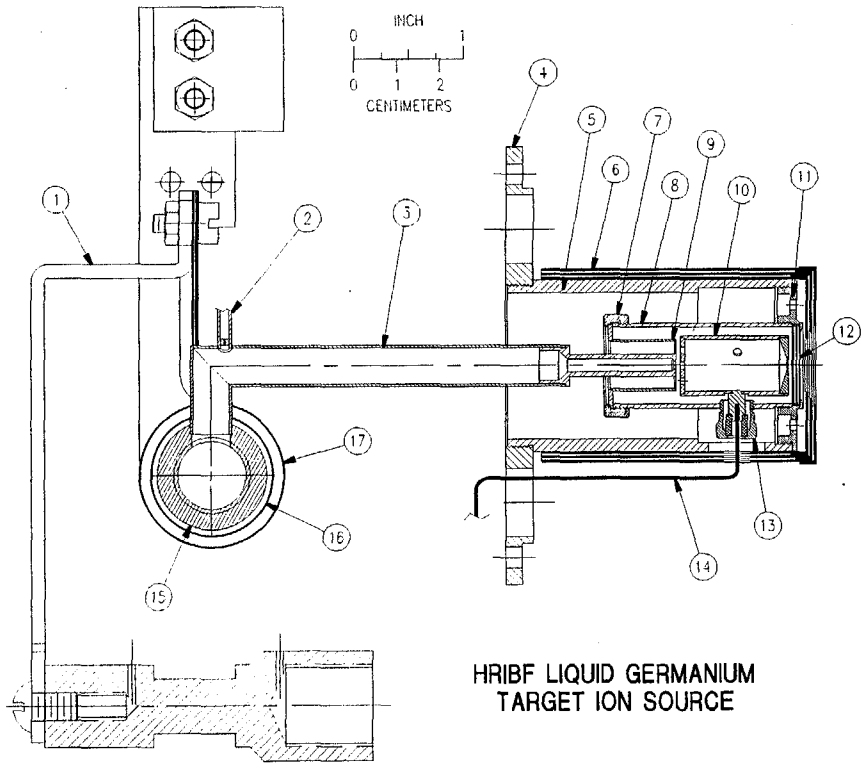
Fig. 2. Release of ^{69}As and ^{70}As. The net count rate of a characteristic gamma ray from each isotope is plotted. No corrections for detector efficiency or branching ratios have been made. These data were taken at the two indicated target temperatures.

Fig. 3. Release of ^{72}As after proton bombardment is stopped. The net count rate for the ^{72}As

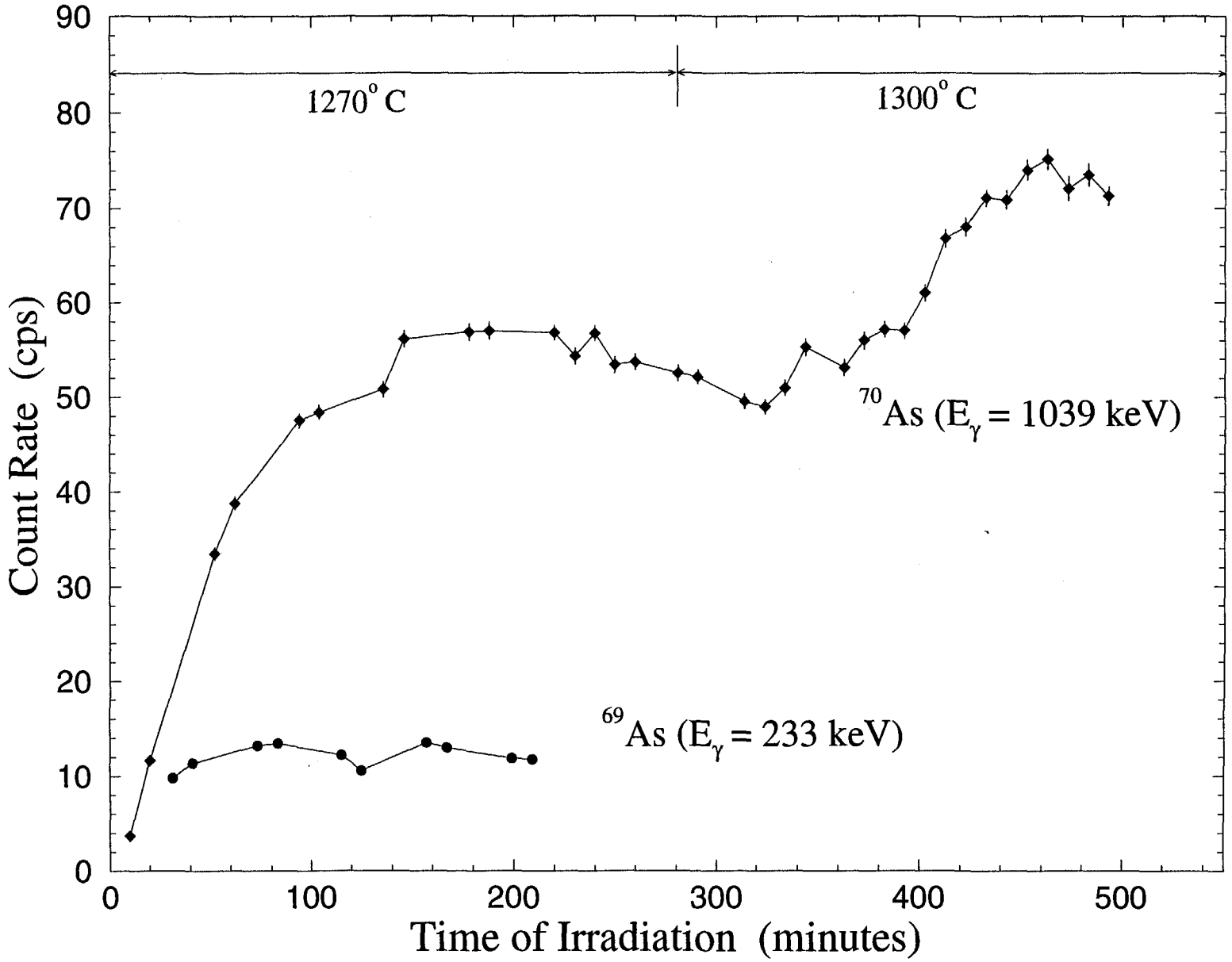
834 keV gamma ray is plotted versus the time with the solid line being an exponential fit to the data. The dashed line represents the half life of the ^{72}As.

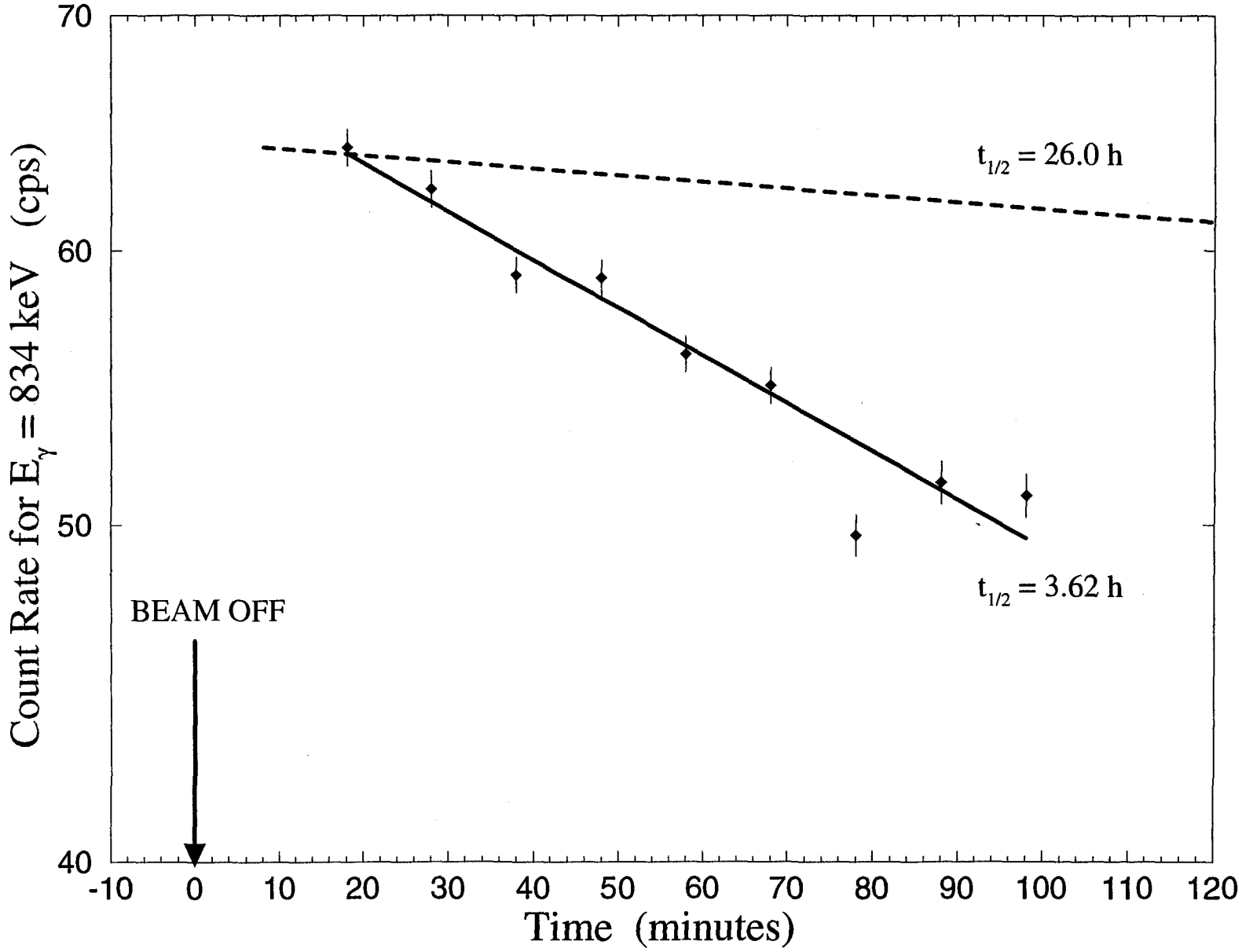
Fig. 4. Normalized count rate for the 1039 keV (^{70}As) and 233 keV (^{69}As) gamma rays plotted versus inverse target temperature. The line is an exponential fit to the data. The counts are corrected for detector efficiency and branching ratio and are normalized to proton intensity of 1 μA.

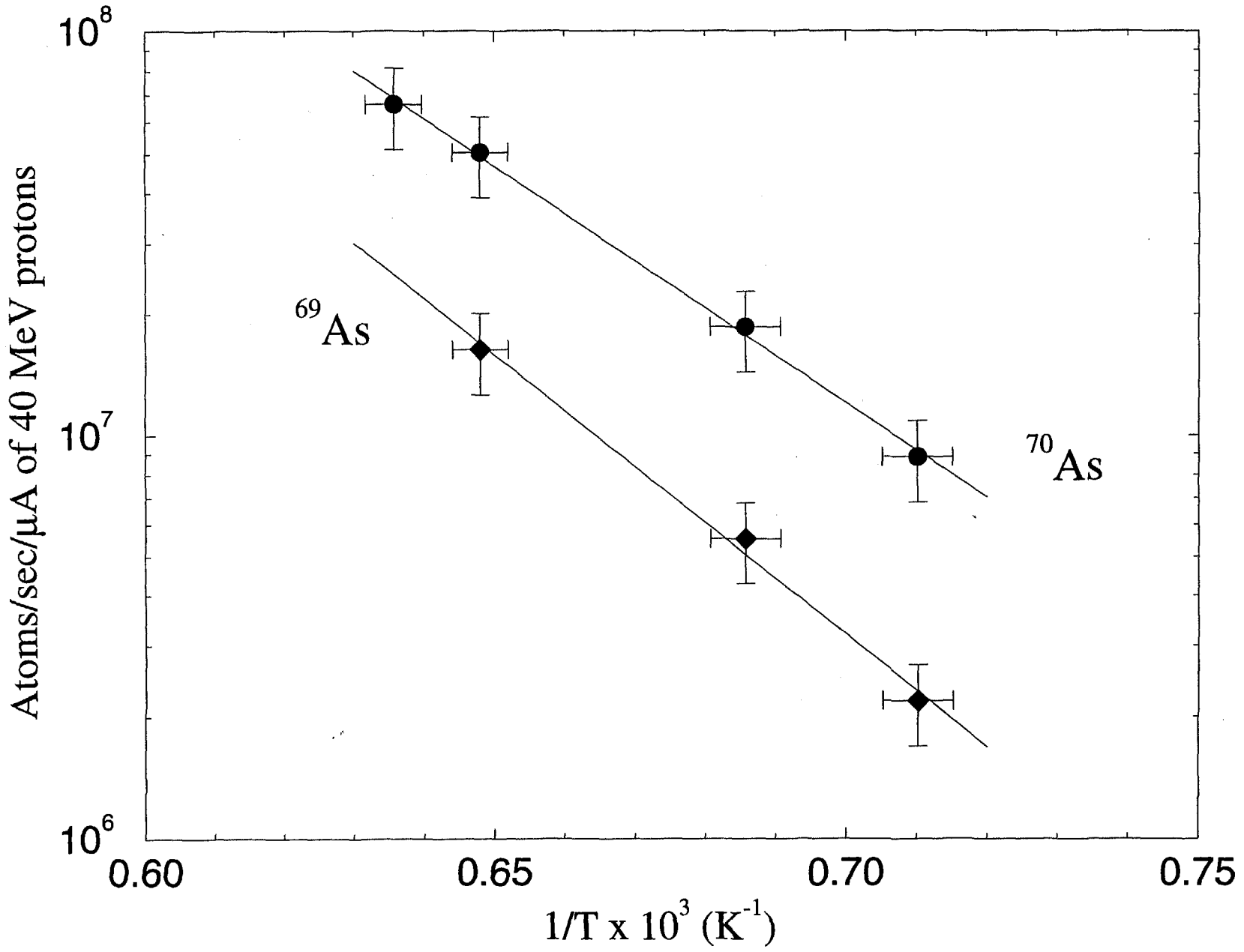
Fig. 5. Release of $Al^{18}F$ after proton bombardment is stopped. The net count rate for the annihilation radiation is plotted versus the time with the solid line being an exponential fit to the data. The dashed line represents the half life of ^{18}F.

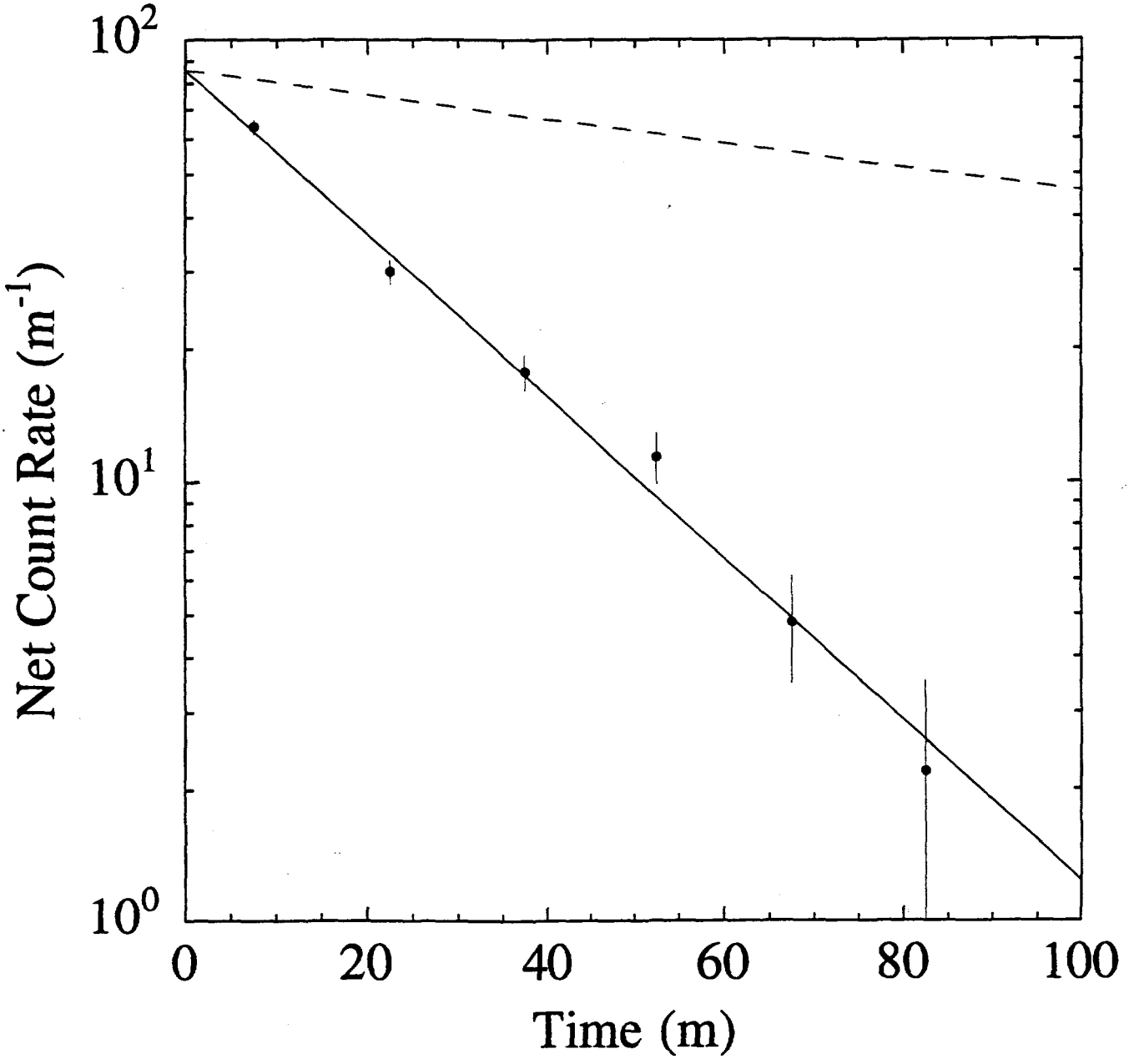


HRIBF LIQUID GERMANIUM
TARGET ION SOURCE


90
80
70
60
50
40
30
20
10
0
Count Rate (cps)
1270° C
1300° C
70As (Eγ = 1039 keV)
69As (Eγ = 233 keV)
0
100
200
300
400
500
Time of Irradiation (minutes)


70
60
50
40
Count Rate for E_γ = 834 keV (cps)
$t_{1/2}$ = 26.0 h
$t_{1/2}$ = 3.62 h
BEAM OFF
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (minutes)


10^8
10^7
10^6
Atoms/sec/μA of 40 MeV protons
^{69}As
^{70}As
0.60
0.65
0.70
0.75
1/T x 10^3 (K^{-1})


10^2
10^1
10^0
Net Count Rate (m^{-1})
0
20
40
60
80
100
Time (m)