A SINGLE PULSE METHOD FOR MEASURING THE RELEASE CURVES OF RADIOACTIVE NUCLEAR BEAM TARGETS

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Abstract

A simple technique for measuring the release curves of radioactive nuclear beams produced by the impact of high energy protons on thick targets is described. It should allow the data for a complete release curve to be collected from the decay of the radioactive beam produced by one short pulse of protons on the target. The method should provide data more quickly than the conventional one, where individual points on the curve are taken in separate proton pulses at time intervals of several seconds or longer. Moreover, the accuracy should be at least as good, if not better in many cases.

1 INTRODUCTION

The time dependant release of radioactive ions from a hot target, bombarded with high energy protons, and followed by a suitable ioniser, generally fit a characteristic release curve [1]. A short pulse of protons on the target gives a current of radioactive ions which initially rises from zero to a peak and then falls, as shown in Figure 1 (typical result for ^{8}Li from a RIST [2,3] tantalum foil target measured at ISOLDE [4]). This release curve can be used to give an indication of the properties of the target and its suitability for the production of rare short lived isotopes. Also, it is hoped that the curve can be used to help in the design of better targets through an understanding of the fundamental process occurring in the target such as diffusion and effusion.

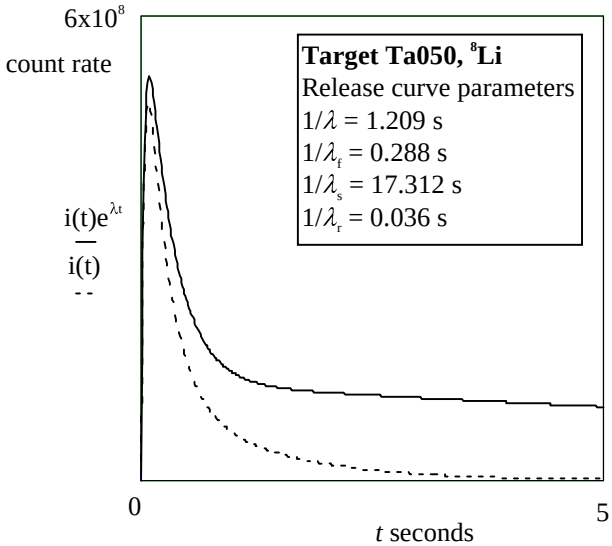

Figure 1. Release curves $i(t)$ with and without decay.

Measurements [1,3] of the release curves from radioactive beam targets have been taken at ISOLDE by putting a single pulse of protons onto the target, transporting a time gated portion of the beam to a tape station and counting the beta decay particles. The number of beta counts, $n(t)$, is plotted as a function of the time delay, t, of the gated radioactive beam, measured from the arrival of the proton pulse on target (t = 0). The measurements are repeated at different delay times to build up a complete release curve

This note considers a different way of measuring the release curves, using all the information in the release from a single proton pulse, and compares the two methods.

2 THE TAPE STATION MEASUREMENTS

Several methods [1,5] of measuring the release function have been reported to have been used at ISOLDE. The tape station system, shown schematically in Figure 2, counting beta decays using a ~4π detector of scintillators surrounding the tape and photomultipliers, will be described here.

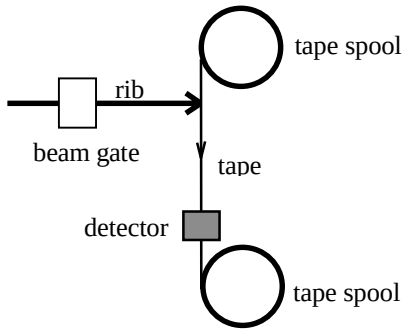

Figure 2: Schematic diagram of the tape station.

Assume that the proton beam hits the target in a short pulse at time zero. The radioactive beam produced by only this pulse of protons is gated to allow a pulse, of length t_c, (the collection time) at time t, to arrive at the tape station and this is deposited on the tape. The tape is then moved over a time t_t so that the radioactive deposit is inside the beta detector array. Then the beta decays are counted for a time t_m, (the measuring time). The detector count $n(t)$ is proportional to the current of radioactive particles that hit the tape at time t in the collection time, t_c. The radioactive beam current on the tape is,

$$i(t) = C\frac{n(t)}{t_c} \qquad (1)$$

If t_c is long, so that the decay or the release function cause appreciably changes to $i(t)$ during the collection, then corrections must be made. Corrections must also be made for the efficiency of the beam transport system from ion source to the tape, the efficiency of the detector and the radioactive decays before the particles reach the tape measuring position. The detector may not only count betas, but also gammas etc. from the decays. Daughter decays and background may need to be considered. The constant C in the above equation takes account of all the corrections.

Repeating the measurement, with the beam gate opening at different times and the tape moved to a new start position, allows a release curve to be plotted.

3 THE RELEASE CURVE

An empirical formula can be fitted to the release curve measurements of the form,

$$p(t) = A\left(1 - e^{-\lambda_r t}\right)\left[Be^{-\lambda_f t} + (1-B)e^{-\lambda_s t}\right] \qquad (2)$$

where $p(t)$ is the probability of release of an particle, $1/\lambda_r$, $1/\lambda_f$ and $1/\lambda_s$ are the rise, fast fall and slow fall time constants respectively and A and B are constants. This formulation fits the data very well in most cases. By definition, the integral of $p(t)$, from 0 to ∞, is 1 and the constant A is given by,

$$\frac{1}{A} = \frac{B}{\lambda_f} + \frac{(1-B)}{\lambda_s} - \frac{B}{\lambda_f + \lambda_r} - \frac{(1-B)}{\lambda_s + \lambda_r} \qquad (3)$$

The actual current of particles measured is,

$$i(t) = c \cdot p(t) e^{-\lambda t} \qquad (4)$$

where c is a number to convert from probability to current and the exponential term, $e^{-\lambda t}$, takes into account the radioactive decay of the particles, time constant $1/\lambda$.

4 THE SINGLE PULSE METHOD

In principle, it is possible to measure the release curve in a single pulse by observing the current of radioactive ions directly. The radioactive decay would be a problem if it caused a change in the recorded current, as would be the case for beta decay used in the usual tape measurement system. An alternative is to implant the radioactive beam current from a single proton pulse onto the tape and then measure only the beta decays in a scintillator at the back of the tape. About half the decays would not be measured because the solid angle presented by the scintillator to the tape can not exceed 2π. The electronics could be made to measure the count rate and/or the integrated count (the yield). Figure 3 shows the system schematically.

The measured counts are the result of the decays from the radioactive beam pulse on the tape. In an element of time, ΔT, at time T, the number of particles hitting the tape is $n(T)\Delta T$. The particles have a decay rate of λ. At some time t, later than T, the decay rate of these particles is,

$$D(t) = c \cdot p(T) e^{-\lambda t} \lambda \Delta T \,. \qquad (5)$$

Integrating over time T from 0 to t, gives the resultant decay rate at time t of all the elements ΔT up to time t,

$$D(t) = c\lambda e^{-\lambda t} \int_0^t p(T)dT \,. \qquad (6)$$

$$D(t) = c\lambda e^{-\lambda t} A \left\{ B\left[\frac{\left(e^{-lt} - 1\right)}{l} - \frac{\left(e^{-\lambda_f t} - 1\right)}{\lambda_f}\right] + (1-B)\left[\frac{\left(e^{-mt} - 1\right)}{m} - \frac{\left(e^{-\lambda_s t} - 1\right)}{\lambda_s}\right] \right\} \qquad (7)$$

where $l = \lambda_r + \lambda_f$, and $m = \lambda_r + \lambda_s$. This decay rate and the usual tape measurement $i(t)$, for comparison, are shown in Figure 4. It will be seen that the peak of the decay curve is 5 times smaller than that of the current, $i(t)$, and delayed by about 1 second - the decay time constant for ^{8}Li.

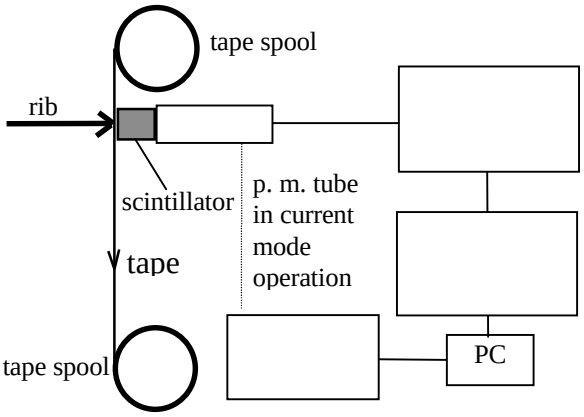

Figure 3: Schematic diagram of the tape station and counting system for the single pulse method.

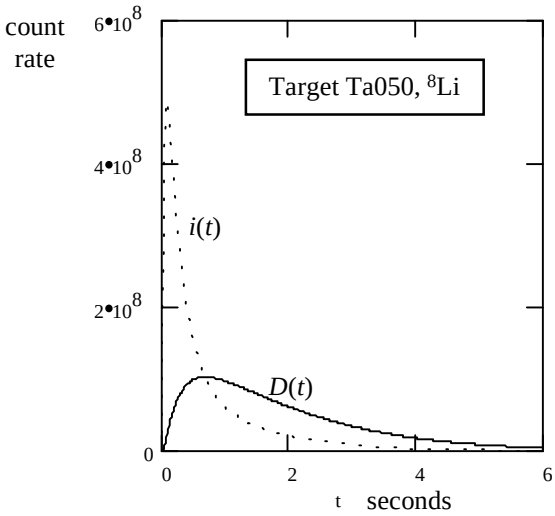

Figure 4: Decay rate $D(t)$, single pulse method. Also, shown for comparison is the current $i(t)$ taken by the conventional ISOLDE method.

Thus by measuring the decay rate of radioactive ions implanted in the tape (produced by a single pulse of protons on the target), it is possible to find directly the parameters of the release curve (2) by fitting the curve (7) to the measurements. It is unnecessary to differentiate the measured curve to reform it into the normal release curve.

5 MEASUREMENT RATE

In the conventional tape measurement, a large number of decays are counted over a long period of time from a small sample of radioactive beam deposited on the tape in a short time and then transported to the counting station. The total count for ^{8}Li is typically up to $4\text{x}10^{4}$ in several seconds, a rate of ~10 kHz. However, much higher count rates are required in the single pulse method. The maximum count rate may be limited by the response of the scintillator, the photomultiplier tube and the electronics. Plastic scintillators can be obtained which give a pulse length of less than 10 ns. Photomultipliers can count at rates over 100 MHz. Electronics are capable of very high count rates, up to 1GHz, into bins of less than 1 μs. Discriminators are limited to about 300 MHz. Overall, system count rates of up to 100 MHz are probably feasible.

Reference to Figure 4 shows that rates of 100 MHz are required. However, the scintillator can only enclose 2π of the tape solid angle and it is assumed that the count rate is halved. So the true count rate for $N(t)$ is ~50 MHz, which is just a little high if pulse pile up is to be avoided. By making the scintillator accept a smaller solid angle the count rate can be reduced for measurements around the peak of the curve.

Alternatively, instead of counting the individual particles, the current flow can be measured by the voltage induced across a dynode of the photomultiplier. This can be displayed and measured directly on a digital oscilloscope and is capable of very high effective count rates, $\sim 10^{10}$. In this case the error due to the number of particles counted is very small. At lower radioactive decay rates, the measurements can revert to counting individual decays.

6 ACCURACY

The accuracy of the measurement is basically due to the statistics of the count. The fractional error in N counts is $N^{-½}$. If the collection time is 4 ms (typical of the example of ^{8}Li shown here) the number of counts measured in a point will be up to $\sim 10^{6}$ for the normal ISOLDE method, while in the same time interval it is only $\sim 2\text{x}10^{5}$ counts (maximum) with the single pulse method. The fractional error in the counts is less than 10% over a range of times from ~0-10 s and ~0-12 s in the two cases respectively.

Typically there will be up to ~40 points measured using the ISOLDE method for practical reasons of limited time, but the measurements are semi-continuous in the single pulse method - for example, with the counting bins set to 4 ms, there will be every 250 points measured per second. It can be shown that this significantly improves the accuracy of calculating the parameters of the release curve from the single pulse measurements. In essence all the data from the release is being used in the single pulse method as opposed to the data only being used from selected small time intervals with the conventional ISOLDE method.

Also, with the single pulse method, it is relatively easy to repeat the complete measurement several times to improve the accuracy, or to rapidly obtain another set of parameters as target/ion source conditions change.

7 CONCLUSIONS

It is possible to make a measurement of the release curve in a single pulse release from the target to a greater accuracy than the conventional method used at ISOLDE with a limited number of measurements. It is particularly useful in providing release curve parameters where any of the time constants are fast, and in particular for fast rise times and short decay times. The method gives an advantage in terms of speed of measurement, looking at slow transients in the target or ion source and the possibility of repeating the measurement many times.

Also, the yield is obtained directly by integrating the total counts obtained in a single proton pulse. The yield is an important parameter since it is the ultimate measure of the speed and success of a target/ion source.

ACKNOWLEDGEMENT

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