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PROPOSAL TO THE ISOLDE COMMITTEE

Identification and decay studies of new, neutron-rich isotopes of bismuth, lead and thallium by means of a pulsed release element selective method

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Abstract

It is proposed to produce, identify and investigate at ISOLDE new, neutron-rich isotopes of bismuth, lead and thallium at the mass numbers A=215 to A=218.
A recently tested operation mode of the PS Booster-ISOLDE complex, taking an advantage of the unique pulsed proton beam structure, will be used together with a ThC target in order to increase the selectivity. The decay properties of new nuclides will be studied by means of $\beta-$, $\gamma-$ and $X-$ray spectroscopy methods. The expected information on the $\beta-$halflives and excited states will be used for testing and developing the nuclear structure models "south-east" of ^{208}Pb, and will provide input data for the description of the r-process path at very heavy nuclei. The proposed study of the yields and the decay properties of those heavy nuclei produced in the spallation of ^{232}Th by a 1 GeV proton beam contributes also to the data necessary for the simulations of a hybrid accelerator-reactor system.

1 Introduction

The nuclide ^{208}Pb is stable and well known as a nucleon system having a magic atomic number Z=82 and a magic neutron number N=126. One expects that the experimental data on the nuclei in the neighbourhood of ^{208}Pb can be explained in a satisfactory way within the shell-model. This region even serves as a textbook example of our good understanding of nuclear structure. This optimistic statement is at least partially true for the nuclei made as proton and neutron holes in the ^{208}Pb core, as well as for some isotopes of elements above lead, where many nuclides have been reached and studied experimentally. Hovewer, there is a clear lack of experimental data for neutron–rich nuclei with $Z \leq 82$ and $N > 126$, see Fig.1. As a consequence, the few existing data are difficult to interprete, and the reliability of further extrapolations is questionable. As an example one may quote the analysis of the r.m.s. radii along Z=82 [1], where the experimental data for stable and neutron deficient isotopes from ^{194}Pb to ^{208}Pb were very well reproduced, while the calculations failed for the lead isotopes heavier than ^{208}Pb. The recent half-life measurement of ^{208}Hg [2] was another surprise. A value of about 40 min obtained for $T_{1/2}$ is much longer than the value of 8.2 min known for the less exotic nucleus ^{206}Hg, the latter having enhanced stability due to the magic neutron number N=126. Such feature is rather unexpected when departing from the $\beta-$stability line.

Good knowledge of the properties of neutron-rich $Z \leq 82$ and $N > 126$ nuclei is not only important for the development and testing of nuclear structure models. The r-process scenario at the top of the nuclear chart depends quite strongly on the nuclear input parameters. For the lead region, this problem was recently investigated [3] by means of the calculations of neutron capture cross section for a series of neutron-rich lead isotopes (from A=208 to A=228). Among the crucial information needed for reliable predictions are the low spin states at low excitation energies in the lead isotopes. Here, beta decay studies can contribute to such data providing the respective parent thallium nuclei can be produced and investigated.

Another motivation for the studies of heavy neutron-rich nuclides is related to the hybrid accelerator–reactor project [4, 5, 6]. Data on the spallation of heavy targets (^{232}Th included) by 1 GeV protons are needed. It concerns not only the primary yields, but also the main decay properties of the produced nuclei like their halflives and decay energies as these determine the time dependence of energy and radioactivity release.

At the former SC–ISOLDE or ISOCELE on-line mass separator facilities operated with high energy light particle continuous (DC) beams, the studies of heavy nuclei at atomic numbers $Z < 84$ have been hampered due to the lack of chemical selectivity which causes very strong isobaric contamination of heavier elements. These products are closer to the used targets of uranium or thorium, and hence have larger yields in the spallation reactions. However, since the move of ISOLDE to the CERN PS–Booster, a pulsed proton beam is provided, which allows in several cases to remove most of the isobaric contamination. The latter are mostly due to very short–lived $\alpha-$emitters ($Z > 83$, $T_{1/2}$ of the order of milli- and micro-seconds) and subsequent decay products. For the mass chains A=215,216 and 217, a delay time t_d of about 200 ms between the proton beam impact and the opening of the beam gate allows for the collection (e.g. t_c of about 1 s) of the longer–lived, moderately fast diffusing isotopes free of isobaric contamination of $Z > 83$ elements - see next section for the encouraging results of the test performed in December 1995.

Therefore, taking advantage of the unique conditions available at the PS Booster-ISOLDE, we would like to perform $\beta-$, $\gamma-$ and $X-$ray spectroscopic studies aiming at the identification and the study of the decay properties of new, neutron rich isotopes of bismuth (Z=83), lead (Z=82) and thallium (Z=81) with mass numbers A=215 to A=218.

2 Recent results of the ThC target test

A test of the release properties and the production yields of the bismuth, lead and thallium isotopes was made in December 1995. A target of ^{232}ThC ($55g/cm^2$) was irradiated with the pulsed 1 GeV proton beam ($2.8 * 10^{13}$ particles per pulse) delivered by PS-Booster with a supercycle of 14.4 s. The pulses were 1.2 s apart (as usual) and up to ten pulses have been sent to ISOLDE (only on 13th December, the last hours before the winter shutdown). The target combined with a hot plasma ion source [7] allowed for a fast, but rather chemically unselective, release of the spallation products. The standard ISOLDE monitor tape station equipped with a 4π ΔE_β plastic counter and a medium size Ge $\gamma-$detector (FWHM=2.8 keV and absolute efficiency of about 1% at 1332 keV) was used for recording of $\gamma-$single or $\beta-$coincident $\gamma-$spectra. The examples of the measured release functions $P(t)$ [8], for lead and thallium, are given in Fig. 2. The release properties for both elements are characterized by the rise time of about 100 ms. They fall down within several hundreds milliseconds allowing for the efficient collection of the radioactive samples even with 100 to 200 milliseconds losses due to the delay time after each production pulse. For the studies of the activities collected at mass numbers A=215, 216 and 217, t_d of 200 ms has been applied in order to suppress the short-lived isobaric contamination, compare e.g. the halflives of A=215 isobars given in Fig.1. Spectacular spectra have been obtained profiting from 10 subsequent proton pulses per supercycle used for sample collection. The $\beta-$coincident $\gamma-$spectra, see Fig.3, recorded at A=215 and A=216 have been dominated by transitions assigned to the β^--decays of the new isotope ^{215}Pb ($T_{1/2}$=35±8 s) and to ^{216}Bi ($T_{1/2}$=2.3±0.1 min). For the A=217 chain, a $\gamma-$transition of 265 keV observed in $\beta-$coincidence and having $T_{1/2}$ of about 75 seconds, is known to de-excite a level in the daugther nucleus ^{217}Po [9]. This allows to report the identification of a new isotope ^{217}Bi.

For ^{216}Bi, the halflives of 6.6±2.1 min [10], and of 3.6±0.4 min [11] have been previously reported based on the experiments at the ISOLDE-3 and ISOCELE facilities having DC proton beams. These results are out of the 2σ limits in comparison to the presently measured value of 2.3±0.1 min. Two $\gamma-$lines at 419 keV and 550 keV, known from the $\alpha-$decay study of ^{220}At as a cascade in ^{216}Po and reported also in [11], were clearly observed during the test run, in addition to even more intense transitions at 224 keV and 360 keV having similar halflife. For ^{216}Bi and ^{217}Bi, the assignment is corroborated by the observed yield curve, shown in Fig.4. The same holds for ^{215}Pb. However, at A=215 the proposed assignment of the observed activity to the decay of a new isotope ^{215}Pb should be unambiguosly confirmed by the observation of the respective X-γ and X-β coincidences (since the excited states of ^{215}Bi are not known from independent experiment).

It is important to notice that the presented and discussed spectra have been obtained with a sample collection during ONLY 12 s, which gives confidence to the proposed extension of these studies to even more neutron-rich new nuclei.

3 Proposed measurements and beam time request

By retainig this element selective method, we would like to perform the decay studies of the A=215,216,217 and 218 samples by means of $\beta-$, $\gamma-$ and $X-$ray spectroscopy using a ThC target. Besides firm identification of a group of new bismuth and lead isotopes, and the studies of their main decay properties, we would like to search for the decay of new neutron-rich thallium isotopes in order to be able to get information on the excited states in the daughter semi-magic lead isotopes. Since the delay/collection/measurement cycle has to be optimized according to the different halflives, at least two shifts are needed per investigated isobaric chain. Therefore we would like to ask for **8 shifts** of beam time.

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Figure Captions

Figure 1

The fraction of the chart of nuclei near the doubly-magic ^{208}Pb. The border line of known isotopes (status November 1995) is given with a dotted line. As an example, the halflife values for the A=215 isobars are listed. Also the halflives measured during the ThC target test at ISOLDE in December 1995 for the new isotopes ^{215}Pb and ^{217}Bi (indicated with the dashed lines) are given together with the corrected $T_{1/2}$ value for ^{216}Bi decay.

Figure 2

The examples of the release function $P(t)$ measured using the activities:
(a) of ^{192}Pb, $T_{1/2}$=37 s
(b) of ^{192}Tl, $T_{1/2}$=10 min
produced during the ThC target test. The delay times t_d after the single proton pulse were from 20 to 6400 ms while the collection time t_c was 3 ms. The $P(t)$ values were obtained from the recorded intensities of the 1195 keV and 423 keV $\gamma-$transitions following the decay of ^{192}Pb and ^{192}Tl, respectively.

Figure 3

The $\beta-$coincident $\gamma-$spectra recorded at the monitor tape station during the 29 s and 202 s measurements of A=215 and A=216 samples, respectively. The samples were collected in the t_d=200 ms / t_c=1 s mode during one supercycle only, i.e. the investigated activities were produced in ThC target by 10 subsequent proton pulses ($2.8 * 10^{13}$ protons each) during 12 s.

Figure 4

The production yields measured for the neutron-rich bismuth and lead isotopes during the ThC target test in December 1995.

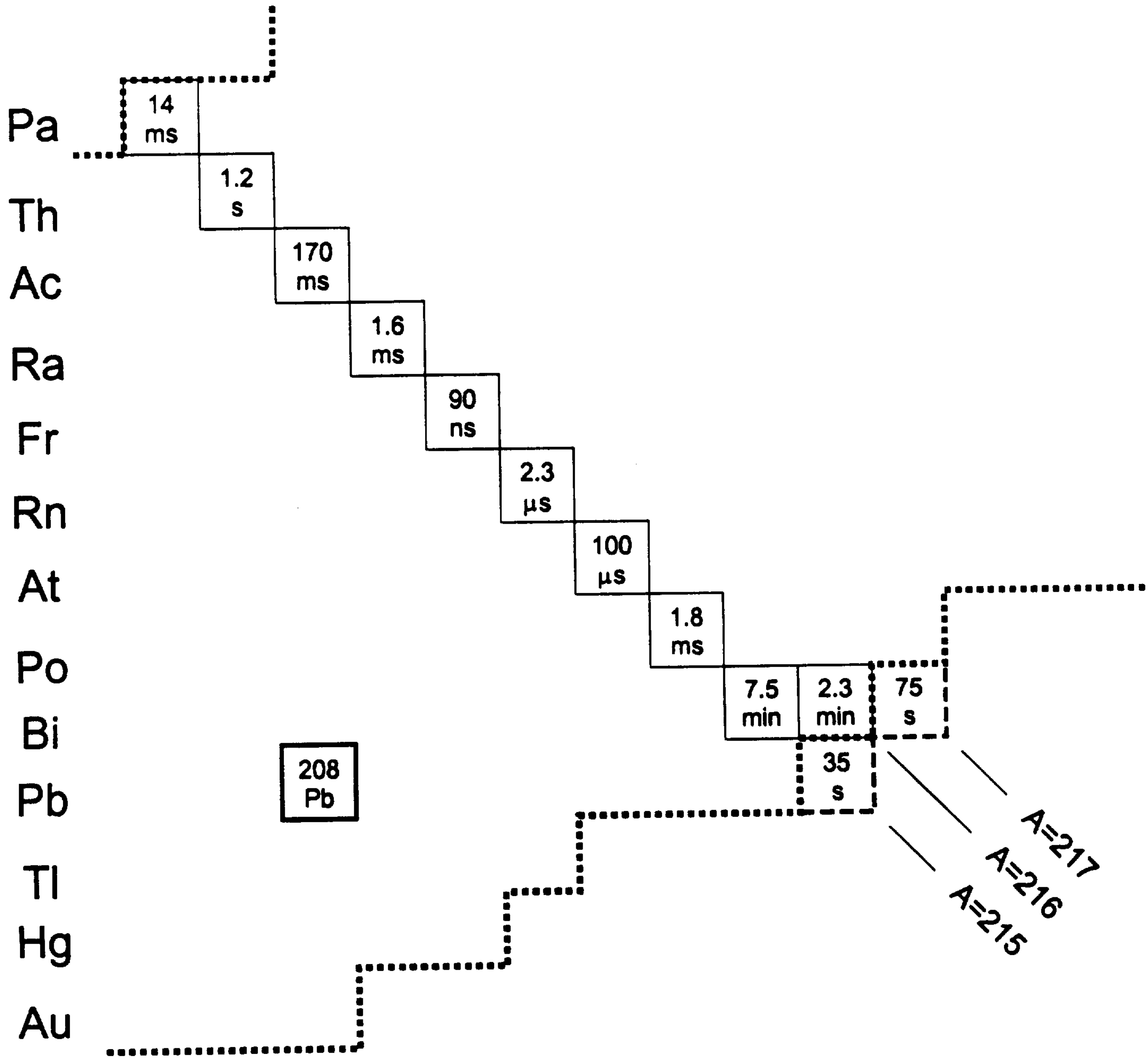

Pa
Th
Ac
Ra
Fr
Rn
At
Po
Bi
Pb
Tl
Hg
Au
14 ms
1.2 s
170 ms
1.6 ms
90 ns
2.3 µs
100 µs
1.8 ms
7.5 min
2.3 min
75 s
35 s
208 Pb
A=217
A=216
A=215

Fig. 1

Fig.2a: 192Pb: Experimental data, and the integrated, normalized P(t)

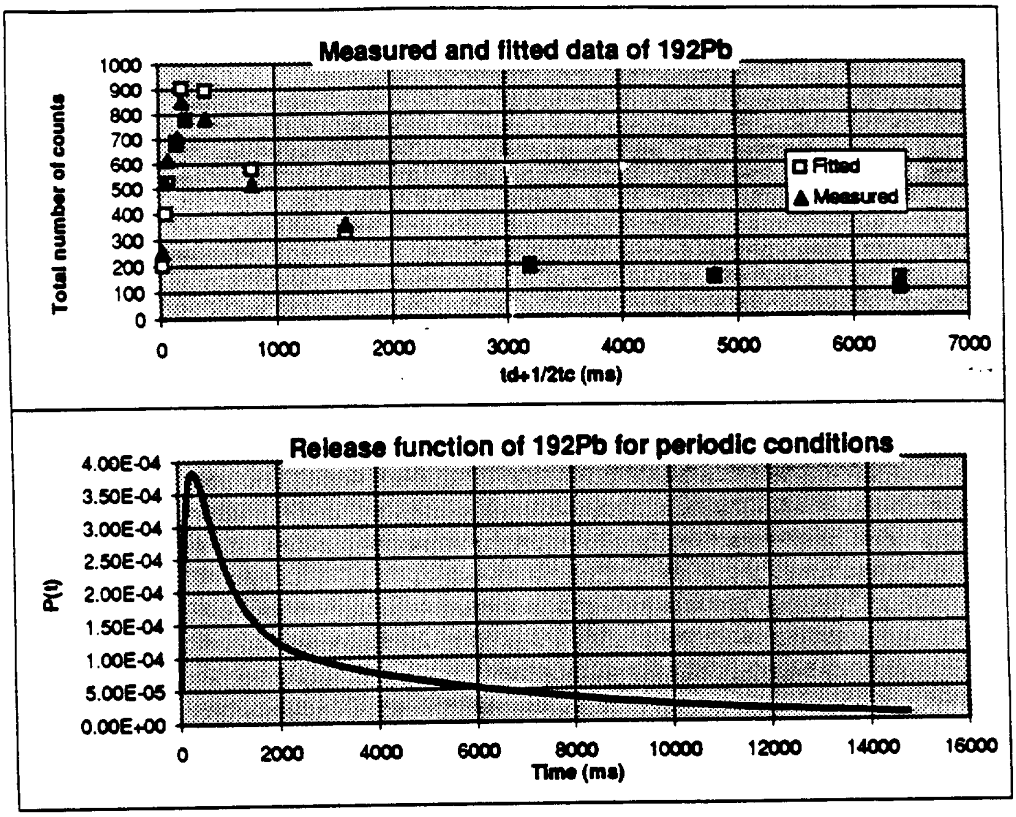
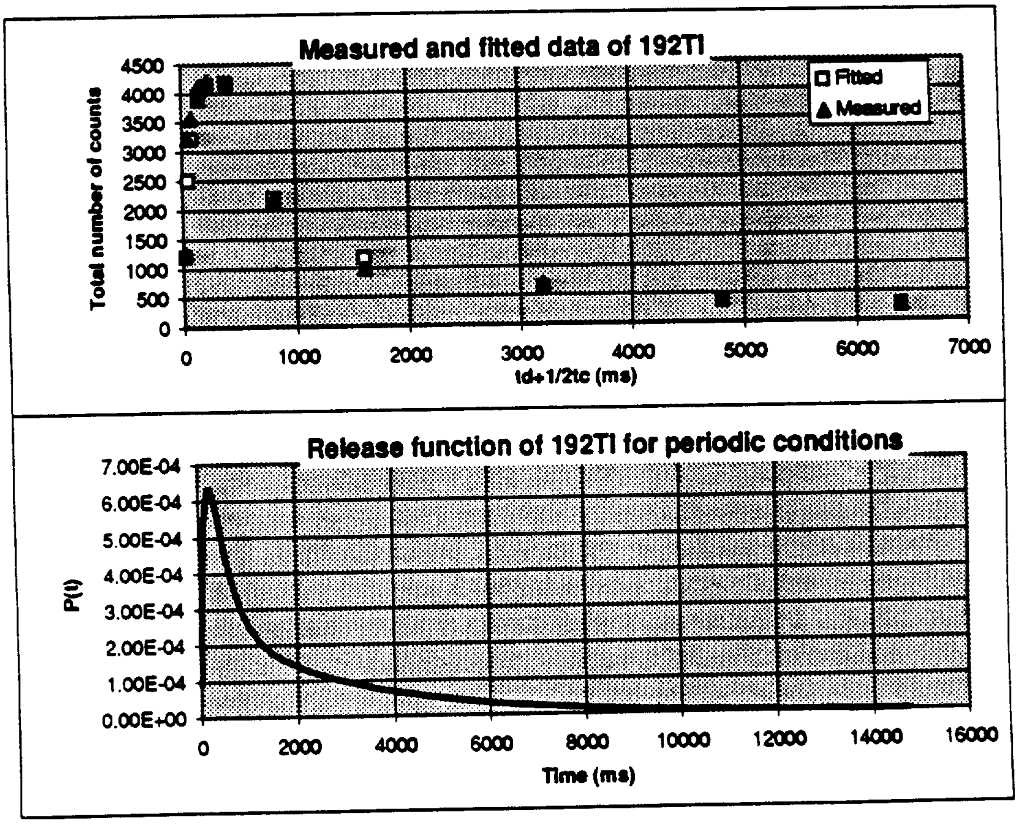
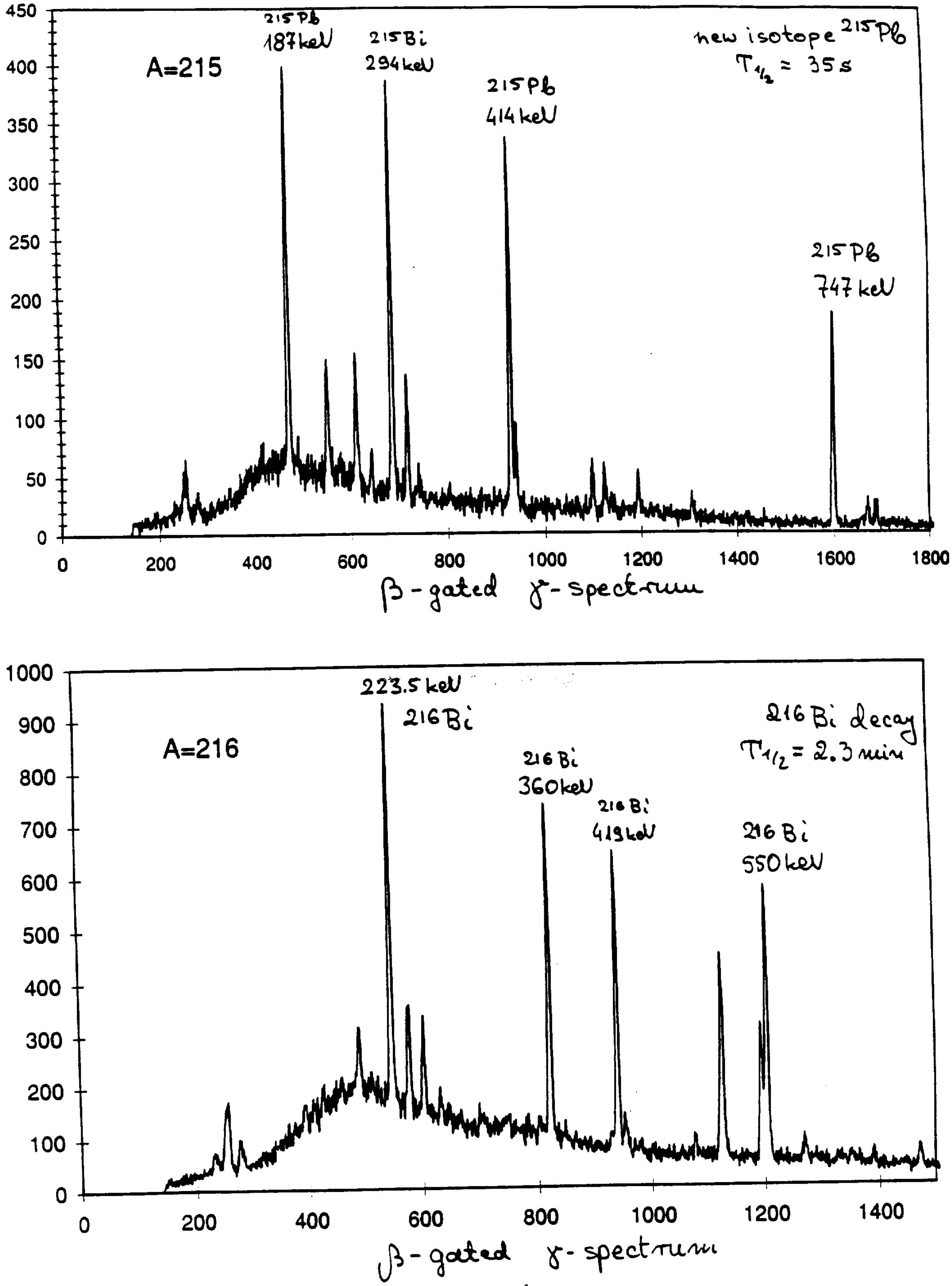


Fig.2b: 192Tl: Experimental data, and the integrated, normalized P(t)





A=215
215Pb 187keV
215Bi 294keV
215Pb 414keV
215Pb 747keV
new isotope 215Pb
T1/2 = 35s
β-gated γ-spectrum
A=216
223.5keV 216Bi
216Bi 360keV
216Bi 419keV
216Bi 550keV
216Bi decay
T1/2 = 2.3min
β-gated γ-spectrum

FIG. 3

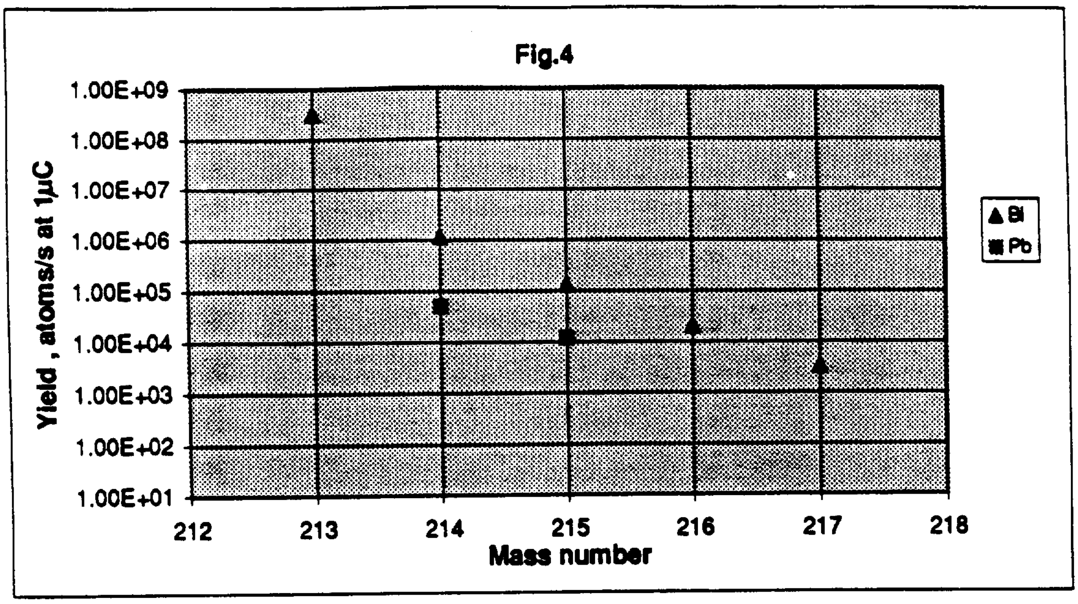


Fig.4
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
Yield , atoms/s at 1μC
212
213
214
215
216
217
218
Mass number
Bi
Pb