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TITLE: A HE-JET SYSTEM TO STUDY SHORT-LIVED FISSION-PRODUCT NUCLEI AT LAMPF

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A HE-JET SYSTEM TO STUDY SHORT-LIVED FISSION-PRODUCT NUCLEI AT LAMPF

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ABSTRACT

Experiments have been performed at LAMPF which demonstrate the feasibility of utilizing a He-jet system to transport fission products to an on-line mass separator from a target chamber mounted in the 800-MeV, >600μA main proton beam. Activities of essentially all elements produced are transported with about 60% absolute efficiency, both for fission reactions and spallation reactions. Transport times are short enough to allow study of activities with half-lives as short as 300 ms. Technical features and scientific possibilities of the system are presented.

INTRODUCTION

The technical feasibility of constructing a He-jet coupled on-line mass-separator facility at LAMPF is under investigation. The He-jet system would rapidly transport short-lived fission and spallation products from a target chamber to the ion source of a remote separator. The He-jet technique, as a method for transporting radioisotopes to an isotope separator, has two main advantages: (1) it provides access to the isotopes of a number of elements that cannot be efficiently extracted for study at any other type of on-line facility, either present or proposed, and (2) low cost. Except for gaseous products, all elemental species are transported efficiently with a He-jet system, including the refractory metals such as Zr, Nb, Mo, Tc, Pd, Ru, and Rh. In contrast, the relatively massive targets that must be used (because of the low beam currents) at other major on-line separator facilities almost completely retain the refractory-metal radionuclides, making these activities unavailable for study. Use of the thin targets required in the He-jet method necessitates a very large incident beam current, of the order of that available at LAMPF, in order to get sufficient yield of individual radioisotopes for detailed study.

The separated ion beams extracted from the proposed separator would be directed to various experimental devices capable of determining basic nuclear properties such as half-life, spin, nuclear moments, mass, and nuclear structure. The data acquired would have broad application to theories of nuclear matter and such related topics as fission-reactor technology and nucleosynthesis of the elements. Emphasis initially would be placed on the study of short-lived neutron-rich fission products. Fission is the only way to reach very neutron-rich nuclei, and among the refractory metals alone it appears that we would have a good chance of identifying and making measurements on at least 150 previously unobserved isotopes. These prospects would inevitably attract a sizeable international user group. In addition, spallation and fragmentation reaction products will make many more previously unstudied nuclei available.

Feasibility studies were initiated at LAMPF in late 1981. These initial experiments, which were performed in a low-intensity (~ 5μA) 800-MeV H^- beam and utilized a rather simple target chamber and activity collection arrangement, yielded very promising results on the activity transport efficiency for both fission and spallation reaction products. The experiments were carried out with little flexibility; only one target chamber pressure was used, only one aerosol (NaCl) was employed, and beam current and aerosol furnace temperature variations were not made over wide ranges. Hence, plans were made for further experimental time at LAMPF in late 1982. The additional experiments were outlined to investigate more thoroughly the influence of beam current variations, aerosol furnace temperatures, and target chamber pressures. It was also proposed that $PbCl_2$ be studied as an alternate aerosol.

In preparation for the second set of experiments, several activities were undertaken. An extensive off-line program to measure aerosol properties established that both NaCl and $PbCl_2$ aerosols had favorable number densities and sizes, and that the capillary transport line had a noticeable, but not drastic, filtering effect on aerosol sizes. A new target chamber concept was developed that allowed the target chamber thickness to be charged for each pressure of interest (the chamber thickness corresponding to the fission-product range in helium at the pressure used). Finally, analytical calculations were made to predict the transit times through the capillary. The above preparations were accompanied by a series of discussions with the LAMPF staff which resulted in (1) the inclusion of space for a He-jet target facility in the plans to reconstruct the beam-stop area of LAMPF, and (2) provision for space in the new LAMPF staging area for an isotope separator system.

NEW RESULTS

The second set of on-line experiments at LAMPF was performed in November, 1982, and most of the experimental objectives were successfully met. The LAMPF operations staff provided an intense, steady, tightly-focused beam which, in effect, made it unnecessary to proceed with plans to continue these studies with a Line-A (main beam) experiment. The major results of the experiments are summarized below.

We utilized a moving tape collector at the collector chamber to rapidly transport collected samples of activity to a well-shielded detector. The tape collector provided us with the capability of observing short-lived activities, of half-life 1 to 5 seconds. The observed counting rates of ^{238}U (p,f) products were very high, and in the resulting spectra, many of the gamma-ray peaks cannot be identified from previously reported studies. The transport efficiencies for the more refractory-element activities averaged about 60%, measured absolutely. At higher target chamber pressures (up to 600 kPa), the short-lived activity levels were much higher than those observed at 200 kPa - a result of the higher flow rates. A comparison is shown in Fig. 1 of the elements observed at LAMPF with those accessible at two other major on-line facilities (ISOLDE [1] and TRISTAN [2]) where fission-product activities are studied.

Transit time measurements were performed for various conditions, the best result being 230 milliseconds for a target chamber pressure of 500 kPa. The calculated prediction for the transit time at this pressure over a capillary length of 22 meters is 320 milliseconds. Since the calculation is based on an average flow velocity in the capillary, the experimental result suggests that the aerosols are "herded" into the central part of the capillary during flow, thus acquiring a larger-than-average flow velocity. The transit time measurements are convincing that activities as short as 300 milliseconds could be readily studied with the proposed He-jet on-line mass separator system.

During variation of the proton beam current over a range of 1.5 μA to 6.1 μA, we observed no variation in the transport efficiency. Post-experiment scans of the beam-induced activity in the ^{238}U target foils indicated that, at the highest current, a beam current density of 45 $\mu A/cm^2$ had been achieved. The highest expected beam current density at LAMPF Line A is about 35 $\mu A/cm^2$; hence, we conclude that the He-jet transport system should function satisfactorily in the intense LAMPF beam, which has been a major concern.

The highest target chamber pressures used (500 and 600 kPa) resulted in capillary flow for which the Reynolds number approached 5000, considerably exceeding conventional laminar flow design limits of about 2200. However, the rate of activity transport continued to increase when these pressures were used. The conclusion is that any turbulence resulting from the high flow did little to disturb the transport of the heavy aerosols.

The temperature dependence of the amount of transported activity verified directly that the activity attaches to the aerosols according to total aerosol surface area, as seen in Fig. 2. This result had been indicated indirectly in other, unrelated studies at aerosol laboratories for aerosols in the size range employed (less than 0.1 μm). Aerosol samples were collected for electron microscopy, and aerosol size distribution measurements were made on activity-loaded aerosols. The electron microscope pictures of the $PbCl_2$ aerosols revealed that the aerosol particles are not spherical, but resemble chains of smaller nucleations -- conglomerations having a high ratio of surface area to mass.

STATUS AND FUTURE PLANS

The availability of H^- beam at LAMPF is too infrequent and too short in duration to be able to make the systematic studies needed to optimize the design for a Line-A target chamber. We have therefore installed a He-jet target chamber in a neutron beam port at the Los Alamos Omega West Reactor (OWR) to continue these studies and arrive at an optimum configuration regarding: 1) the effect of using multiple capillaries rather than only one;

2) capillary and He supply line placements which maximize the target volume sweep rate; and 3) evaluation of three candidate aerosol materials, NaCl, $PbCl_2$ and KCl, to determine which will provide the highest transport efficiency.

Results to date include overall transport times, using a 22-m transport line and a target chamber with up to 5 exit capillaries and up to three inlet lines. Although all of the data have not undergone analysis, the preliminary indication is that a single exit capillary and two inlet lines provide the optimal configuration for use under the LAMPF Line-A conditions. Figure 3 shows preliminary data for two sizes of exit capillary. The initial onset of activity transport is clearly evident, as is the rapid "sweep" of the target chamber (of the order of 2 s). Based on these early results, we are confident that we will be able to study fission-product activities as short-lived as 0.3 s at LAMPF . We will continue the OWR experiments in order to study the transport of activity under different target chamber conditions, using each of the aerosols of interest (the present studies have utilized only NaCl).

The data acquired thus far have convinced us that the proposed He-jet/mass-separator system is technically feasible. With respect to the scientific justification for proceeding with the project, the measured transport times and estimated cross sections at 800 MeV clearly indicate that a large number of previously inaccessible short-lived fission products could be isolated for detailed study at the LAMPF facility. For example, Fig. 4 displays regions of nuclei that are essentially unexplored but would become available at LAMPF. The new data that could be acquired in these rather large regions would represent a major extension of our knowledge of nuclear behavior.

References:

[1] H. L. Ravn, "Experiments with Intense Secondary Beams of Radioactive Ions," Phys. Reports 54, 202 (1979).

[2] F. K. Wohn, "TRISTAN II- Extension of Capabilities to Non-Gaseous Fission Products," Proc. Isotope Separator On-Line Workshop, Brookhaven National Laboratory, October 31-November 1, 1977, Brookhaven National Laboratory Report BNL-50847.

[3] K. Takahashi, M. Yamada and T. Kondoh, "Beta-Decay Half-Lives Calculated on the Gross Theory," At. Data Nucl. Data Tables 12, 101 (1973).

FIGURE CAPTIONS

Figure 1. Periodic chart showing elements directly produced in LAMPF He-jet feasibility experiment and at the on-line isotope separator facilities ISOLDE [1] and TRISTAN [2].

Figure 2. $PbCl_2$ aerosol number density and surface area as function of temperature, and activity transported at LAMPF vs. temperature.

Figure 3. Activity multiscale data for 2 sizes of exit capillary. The 2.4-mm capillary data have been multiplied by a factor of 1.5 to compensate for the reduced fission fragment stopping volume at 250 kPa compared to 500 kPa.

Figure 4. Chart of nuclides illustrating present limits of measured masses, 300-ms half-life limits (according to gross theory of beta-decay [3]), and regions of nuclei uniquely available with a He-jet system at LAMPF.

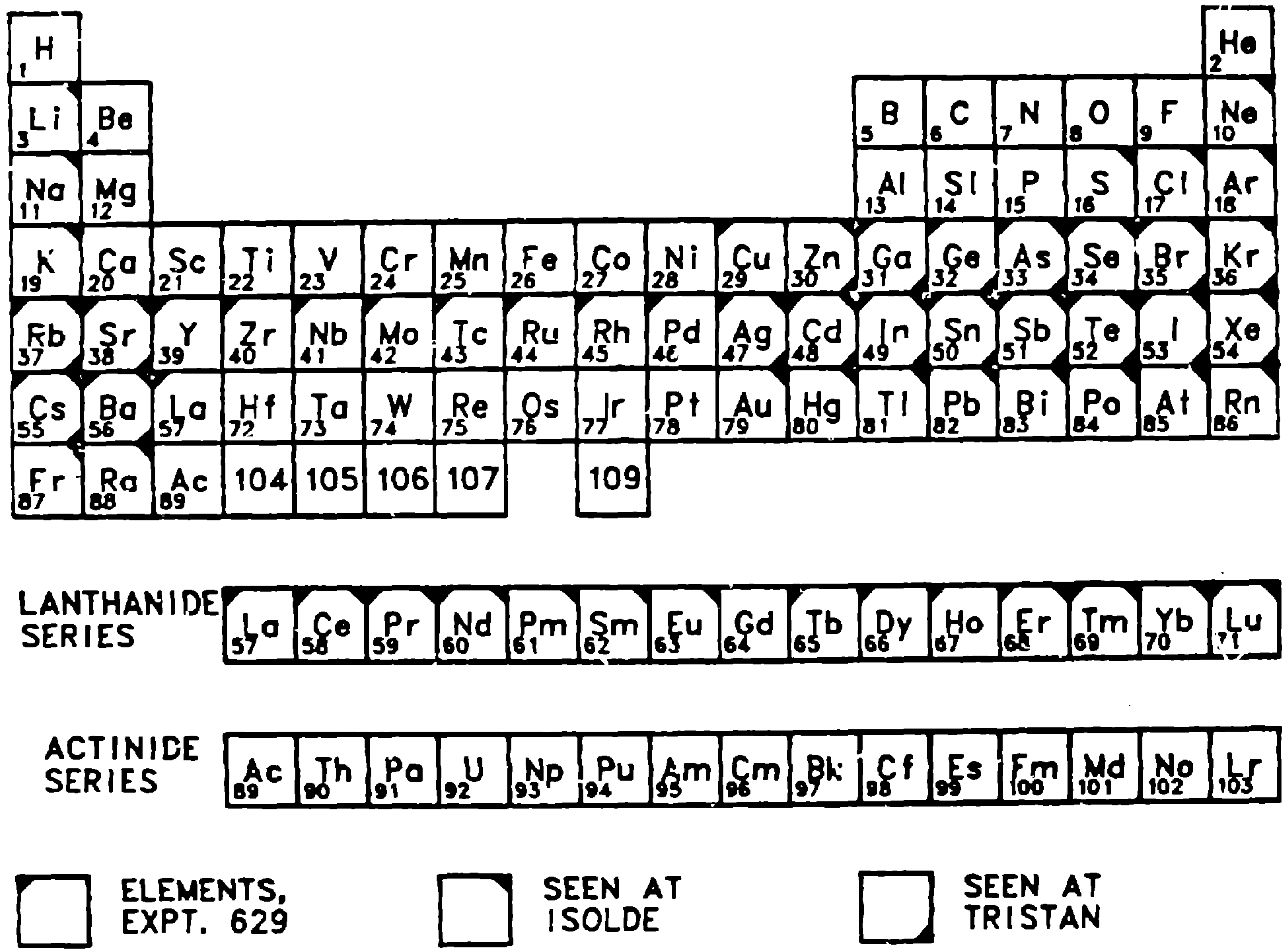
1 H
2 He
3 Li 4 Be
5 B 6 C 7 N 8 O 9 F 10 Ne
11 Na 12 Mg
13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
55 Cs 56 Ba 57 La 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
87 Fr 88 Ra 89 Ac 104 105 106 107 109
LANTHANIDE SERIES
57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu
ACTINIDE SERIES
89 Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr
ELEMENTS, EXPT. 629
SEEN AT ISOLDE
SEEN AT TRISTAN

Fig. 1

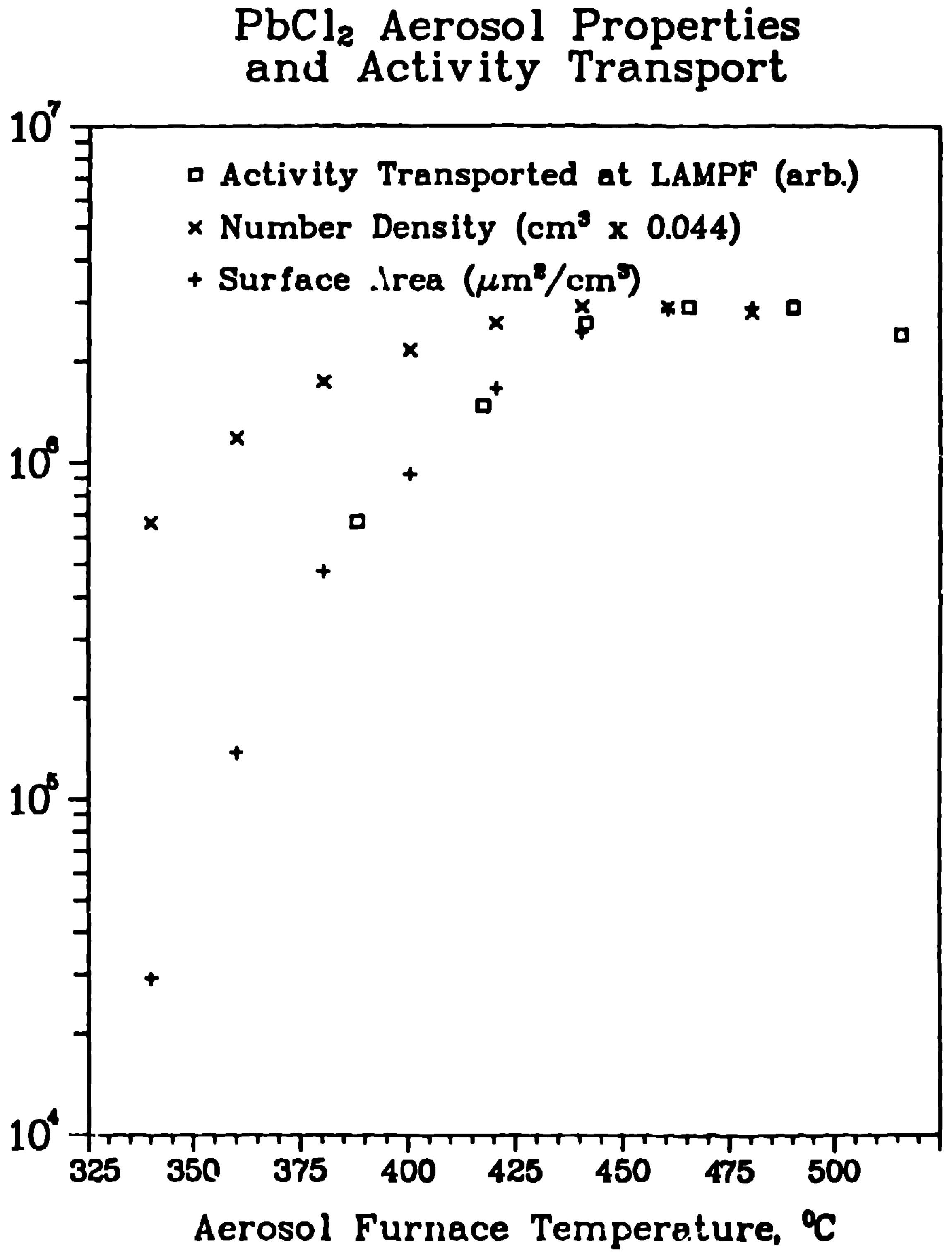
PbCl2 Aerosol Properties
and Activity Transport
Activity Transported at LAMPF (arb.)
Number Density (cm3 x 0.044)
Surface Area (μm2/cm3)
10^7
10^6
10^5
10^4
325
350
375
400
425
450
475
500
Aerosol Furnace Temperature, °C

Fig. 2

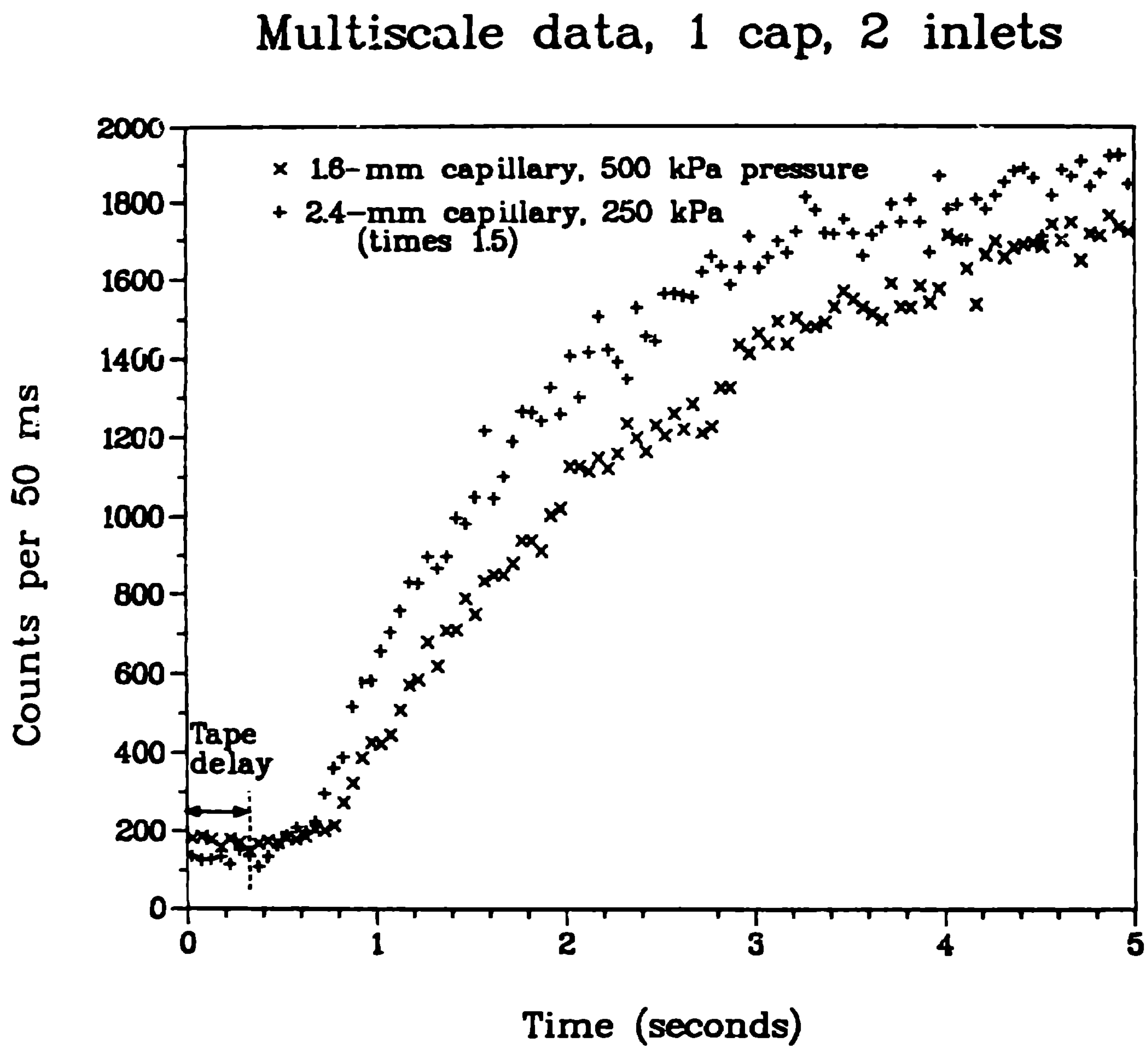
Multiscale data, 1 cap, 2 inlets
× 1.6-mm capillary, 500 kPa pressure
+ 2.4-mm capillary, 250 kPa
(times 1.5)
Tape delay
Counts per 50 ms
Time (seconds)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
1
2
3
4
5

Fig. 3

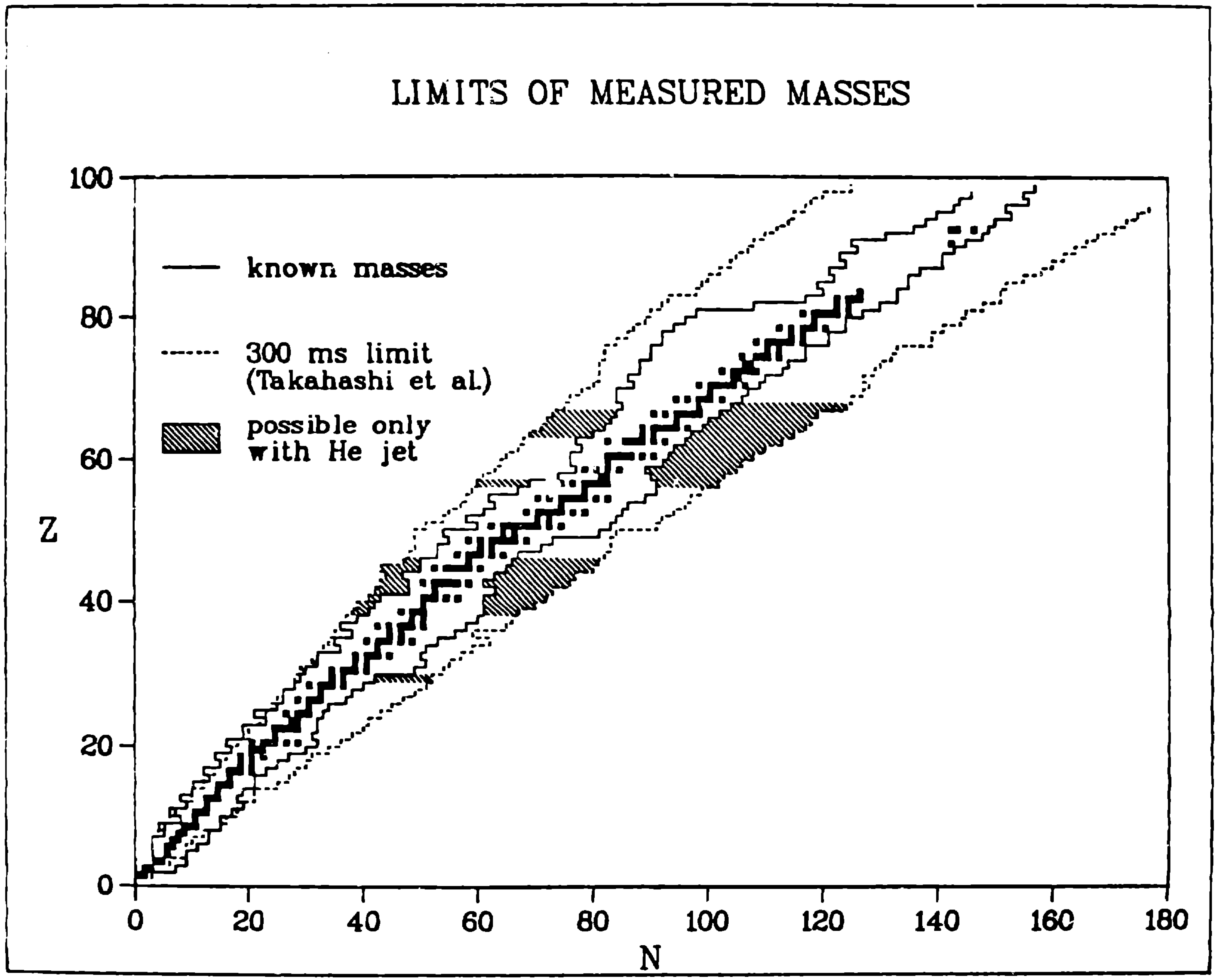
LIMITS OF MEASURED MASSES
known masses
300 ms limit
(Takahashi et al.)
possible only
with He jet
Z
N
0
20
40
60
80
100
0
20
40
60
80
100
120
140
160
180

Fig.4