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PROGRESS REPORT
1980

FOSTER RADIATION LABORATORY
DEPARTMENT OF PHYSICS
McGILL UNIVERSITY

CONTENTS

I INTRODUCTION

This report covers the period from November 1979 to October 1980. It summarizes the operation and development of facilities in the Foster Radiation Laboratory and the research carried out using these facilities.

There are two main groups of personnel using the Laboratory facilities. The resident personnel who occupy office space in the Laboratory and the non-resident personnel, who come from the Chemistry Department and the Montreal Neurological Institute. The resident personnel are charged with the responsibility of operating and developing the facilities in the Laboratory. It has been the tradition in the Laboratory that the research personnel associate with each other to form groups to investigate particular problems of their common interest. Collaboration with researchers outside the Laboratory is also common and frequent.

The upgrading process for the synchrocyclotron is continuing. Among the improvements implemented during the past year, two specific ones should be mentioned. One is the successful operation of a prototype radial extraction ion source, and the other is the substantial reduction of the external beam emittance. The first one resulted in a reduction of radial oscillation of the alpha beam and the subsequent improvement in extraction efficiency. The other is largely responsible for the reduction of the background in the external beam hall. With the stochastic beam stretcher, in-beam γ-spectroscopic experiments were carried out.

Last December an independent temperature and humidity regulated computer room was partitioned from the control room. This has improved the performance of the PDP-15 computer. At present, the data acquisition peripherals are being systematically converted to CAMAC compatible modules. The PDP-11/34 computer is still mainly being used for off-line data analysis.

A low background cage has been constructed for on-line γ-spectroscopic studies. A γ-ray multiplicity filter system was installed and has been used in the experimental studies. An improved target-ion source for the on-line isotope separator was installed. A ΔE-E telescope was used for beta-end-point energy measurements and its response function was determined. The horizontal-bore superconducting beta spectrometer was constructed and is at present undergoing thermal and vacuum testing.

The main research activities in the Laboratory continue to be the studies of nuclear properties far from beta stability, complex nuclear reactions and the nuclear fission mechanism. The positron emission tomography (PET) program progressed well. The double-ring camera has been used extensively for the study of three dimensional blood flow in the brain. The installation of the mini-cyclotron at the Montreal Neurological Institute is at its final stage of preparation, and will be carried out in the near future. Another project in applied physics got underway last summer. In collaboration with personnel from the Royal Victoria Hospital, the properties of a thermal neutron activation facility using Pu-Be sources was being investigated. Hopefully, this will lead to a reliable method for the determination of total body nitrogen content.

In September, 1980, Dr. S.K. Mark returned after his sabbatical leave, and Dr. R.E. Bell, former Director of this Laboratory (1960-68) and Principal of McGill University (1969-79) rejoined the Laboratory. Dr. J.E. Crawford went on sabbatical leave 1980-81. Dr. M. Chatterjee returned to Saha Institute, India, in October 1980 and Dr. T. Nagarajan of Madras University, Madras, India, joined the Laboratory as a Visiting Scientist.

The operation and development of the facilities in the Laboratory were supported by a core grant from the Natural Science and Engineering Research Council (NSERC) of Canada. In addition, direct financial contributions from the University were also received. All the research activities were funded through grants from NSERC, the Medical Research Council and le Ministère de l'Education du Québec. The generosity of these supporters is gratefully acknowledged.

II LABORATORY OPERATION and DEVELOPMENT

A. The Synchrocyclotron

The synchrocyclotron is a K=100 accelerator, capable of accelerating Z=1 and 2 projectiles to maximum kinetic energies of KZ^2/A MeV; that is 100 MeV protons, 133 MeV, ^{3}He, etc. The nominal internal beam intensities are 2 μA for protons and deuterons, 1 μA for helium projectiles, while the external beam intensities are 200 nA and 30 nA, respectively. The synchrocyclotron has a pulse rate of 500 pps and the external beam bursts are about 20 μs long, modulated by an RF microstructure. To overcome this limitation of low duty cycle, a stochastic beam extraction system has been installed. This system randomizes the extraction of the beam so that it resembles a continuous beam. With this system in operation, the average extracted beam intensity is reduced to about 30% of the pulsed beam. However, this reduced beam intensity is more than sufficient for a typical on-line spectroscopic experiment.

(a) Synchrocyclotron Operation

During the past year, there were three scheduled shut-downs totalling 8 weeks for various upgrading processes. The general distribution of the cyclotron operation hours are summarized in the following table:

Total Scheduled Time 44 Weeks

Regular Maintenance	400 hours
Upgrading	600
Proton Beam	1800
Deuteron Beam	50
Helium-3 Beam	50
Alpha Beam	1400
Down Time Due to Faults	500
Total:	4800 hours

About 80% of the beam time was used for the nuclear physics program and the remaining 20% was used by researchers from the Chemistry Department and the Montreal Neurological Institute.

Despite the relatively long scheduled shut-down periods, the total cyclotron operating hours remained essentially the same as the previous years. As anticipated, the cyclotron hours devoted to the alpha beam increased substantially during the past year, and only limited testing was carried out for helium-3 beams. The down time due to faults has increased. This is mainly due to the inadequate cooling capacity of the heat exchanger. This is particularly severe during continuous operation on hot summer days. Most of this down time is due to failure of the RF amplifier of the beam stretcher system. Aside from this, the cyclotron operated satisfactorily.

(b) Machine Development

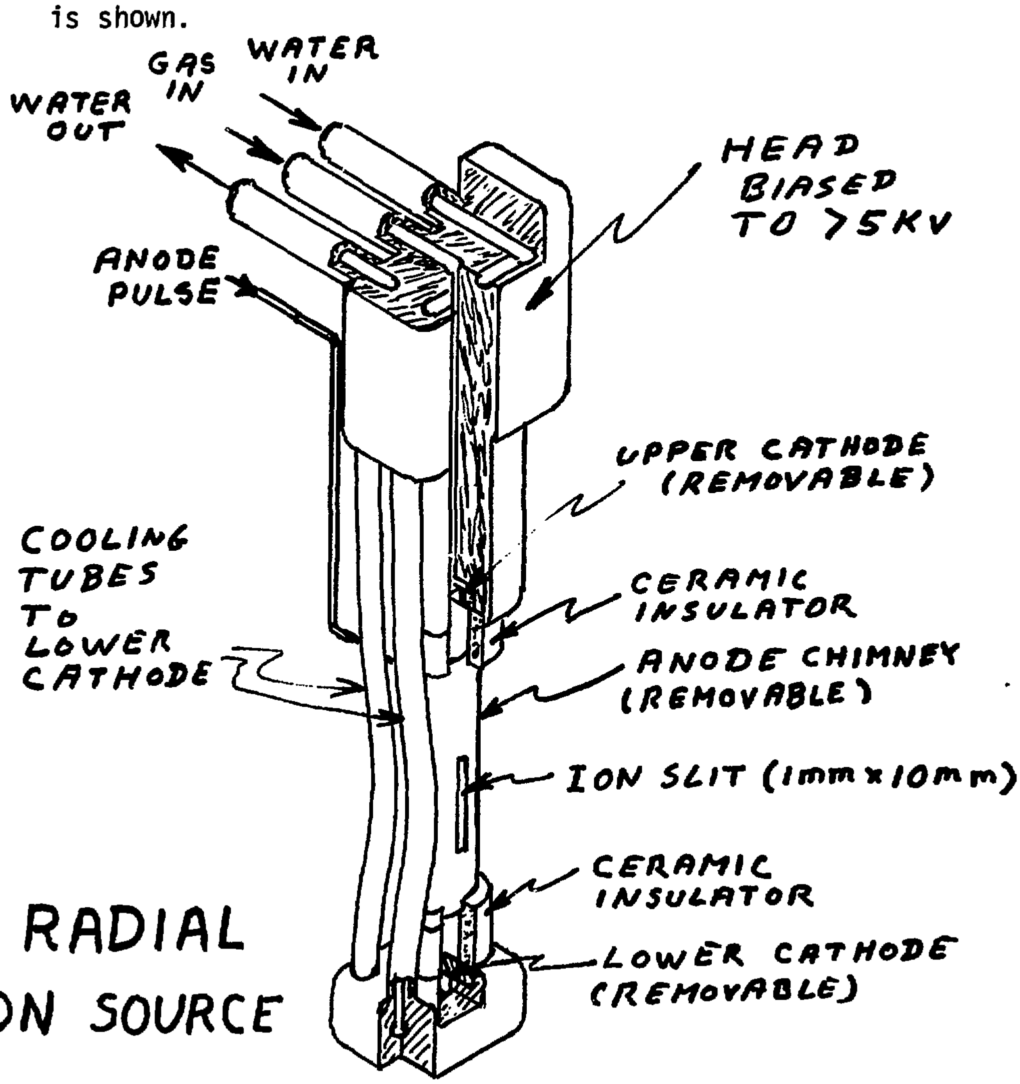
During the past year, several upgrading steps have been completed or initiated. They are:

(1) Improvement of Cyclotron Vacuum

Two new 16" diffusion pumps with cooling baffles and automatic gate valves were installed. Without cooled baffles, the cyclotron vacuum improvement is about 20%. Cooling of the baffles reduces the vacuum further, but the cost of liquid nitrogen is high and the improvements to the alpha beam operation is marginal. Therefore, they are not used in regular operation. The automatic gate valve proved to be very useful: the down time due to accidental vacuum leaks or power failures was reduced.

(2) Ion Source Development

A radial extraction ion source with d.c. bias to inject particles into the median plane of the cyclotron was constructed and successfully tested. It reduced the radial oscillation substantially and improved the performance of the cyclotron for alpha beam operation. With the 6 kV bias, the internal alpha beam is about 250 nA. This current is low compared to the old axial ion source (~1 μA), but the effect on internal isotope production rate is minimal. The external beam extraction efficiency is improved to about 15%. A sketch of the ion source is shown.



RADIAL ION SOURCE

After about 4 months of operating experience with this prototype, a new ion source was constructed. The new design simplifies the regular servicing procedures and also provides better protection against electrical discharges of the source to ground due to the d.c. bias. This new ion source is now the regular source for alpha particle beam operation.

Presently, we are working on modifications of the source for the acceleration of $^{12}C^{4+}$ and protons. The production of useful amounts of $^{12}C^{4+}$ ions will place greater demands on the ion source power supply and the source biasing system. The acceleration of protons will require modification of the ion source support structure to prevent RF resonances within the frequency operating range for protons. These problems are being studied and methods to overcome them will be incorporated in the final design.

(3) External Beam Alignment

A passive sextupole was designed and installed at the exit of the magnetic extraction channel to correct for the known second order distortions in the emittance of the extracted beam. (These effects arise from the non-linearity in the field gradient within the extraction channel). After only two iterations, the correct sextupole strength and alignment were established. The effective emittance of the beam was reduced to about 10 mm-mrad, and considerable improvement was achieved in the small fraction of the beam that forms a background "haze" in the beam pipe. These improvements mean that it is now possible to use the present small quadrupole set in the cyclotron vault to focus the beam to a reasonable size in the middle vault. This will reduce considerably the cost for moving the on-line isotope separator to this site.

Full use of the improved quality of the external beam cannot be made in the external beam hall at present because of the limitations in the 30^0 and 45^0 magnet system. These limitations are primarily small apertures and an over-reliance on edge focussing to achieve the proper delivery of the beam to the external beam vault. However, the improved beam emittance does substantially reduce the background in the external beam hall, although, for degraded beam operation, a low background cage is necessary to reduce the background to tolerable level.

(4) R.F. Feedline Modification

After about a year of operating experience with the prototype R.F. feedlines for heavier ion acceleration, the entire feedline and the feedthrough system into the cyclotron is being redesigned. The purposes of the present modifications are:

(i) to eliminate a dangerous sparkover problem at the R.F. feedthrough into the cyclotron tank;

(ii) to increase the Q of the system for more efficient use of R.F. power;

(iii) to improve the cooling of inner lines particularly for heavier particle operations;

(iv) to facilitate the chargeover procedure from one particle to another;

(v) to adapt the system for accelerating $Q/A = 1/3$ ions;

(vi) to raise the dee voltage and reduce the rate of frequency swing for ions of $Q/_A < 1$.

Preliminary indications show that a considerable improvement in beam intensities should be possible. The actual conversion is in progress and testing of light-ion acceleration will start in the near future.

B. <u>Data Handling Facilities</u>

The data handling facilities in our Laboratory are centered around a PDP-15 and a PDP-11/34 computer. The PDP-15 is primarily used for on-line data acquisition, while the PDP-11/34 is mainly used for off-line data analysis.

Last year, a portion of the cyclotron control room was partitioned off. This enclosed area has an independent temperature and humidity regulation, and is used to house the PDP-15 computer and the data acquisition system. A remote terminal with duplicating switch register, display scope and light pen was installed at the cyclotron desk to facilitate the control of on-line data acquisition.

The PDP-11 computer is located in the second floor counting room. Its memory is being expanded to 124 k, the maximum that can be used with the processor. A LeCroy 3512 ADC has been acquired to provide a limited data acquisition capability using this computer. Software development is continuing.

During the past year, a deterioration in the performance and reliability of the PDP-15 has been noticed. The failures were intermittent and therefore very difficult to locate and rectify. To safeguard against the possibility of sudden major failure of the PDP-15, and to plan for adaption to future data handling systems, we have started to convert the present data acquisition peripherals to CAMAC compatible formats. Separate CAMAC memory modules and a micro-processor-based auxiliary controller is planned to control the experiment and to transfer data to the remote PDP-11 computer. The necessary hardware to perform these operations is being constructed.

C. Other General Experimental Facilities

(a) Isotope Separator

The isotope separator can be used in two different modes: as an isotope separator or as a mass spectrometer for fission yield studies. It has a surface ionization source capable of producing separated Ga, Rb, In and Cs isotopes from fission yields. The Ga isotope yield is low, not yet sufficient for spectroscopic studies.

At the collection position of the separated isotopes, several adaptations were made to allow setting up of various β-γ and γ-spectroscopic experiments. A ΔE-E telescope using a 15 mm Ge(HP) detector has been constructed and the beta response function for this detector set-up has been studied. A mini-orange magnetic filter for conversion electrons has also been added and its transport efficiency is being determined.

(b) Superconducting Solenoid Beta Spectrometer

There exists in our Laboratory two such spectrometers: a 1½" vertical-bore soloid with a 300 mm^2, 10 mm thick Ge(HP) detector, which has been used extensively in the past few years and a 4" horizontal-bore solenoid with a 500 mm^2, 15 mm thick Ge(HP) detector. The performance of the latter spectrometer is being tested.

The vertical-bore spectrometer is still functioning. The increase in liquid helium consumption noticed last year did not become worse and several experiments were conducted without unexpected interruptions.

The construction of the horizontal-bore spectrometer has been completed. The superinsulation foil used for the construction worked very well and the liquid helium consumption is reasonable ($\lesssim 1\ell$ per hour). The magnetic field mapping of the solenoid has been obtained and the system is being tested for thermal and mechanical stability. It is expected that this spectrometer will be fully operational in the near future.

(c) On-Line γ-Ray Spectroscopy Facility

The on-line γ-spectroscopy facility is now fully operational. A low background cage with R.F. signal shielding has been constructed to house the experimental set-up. A γ-ray multiplicity filter system has been built. It consists of six NaI detectors and two Ge(Li) detectors, and a data-accumulation system to record each pair of γ-rays detected in coincidence in the Ge(Li) detectors together with the number of NaI detectors which were simultaneously triggered. A degraded alpha beam with energy of 50 MeV or higher can be delivered to the target position with reasonably low background for on-line spectroscopy work. An on-line conversion electron set-up using a cooled Si detector is being constructed. This will provide supplementary information to the angular-correlation measurements.

(d) Helium-Jet System for Internal Bombardment

The helium-jet transport system has largely replaced the pneumatic target transport system for delivery of radioactive sources from internal bombardments. During the past year, it was observed that the reliability of the system during long bombardments is dependent on the oven temperature of the aerosol generator, and the helium flow rate. Furthermore, the salt aerosol that was used produced too thick a target for charged particle detection. Further experimentation is underway to use other forms of aerosol to overcome these deficiencies. A skimmer system has been built and tested. A filter magnet has been added, in order to reduce the positron background during charged-particle detection.

(e) Penumatic Target Transport Systems

The two pneumatic target transport systems are still operational but the demand for their use is diminishing. During the past year, the 1" diameter, straight path, system was used for gas target work but the other 3/8" system was only used to test the target container tube material for ^{3}He and ^{4}He bombardments.

III PROGRESS IN RESEARCH*

1. Structure of Neutron Deficient Nuclei Near N=50

(S.K. Mark and K. Oxorn)

Properties of unstable neutron-deficient nuclei with N in the vicinity of 50 are being studied by means of beta-decay spectroscopy techniques. The beta decaying nuclei were produced by the (p,xn) reactions on appropriate targets and then transported by a helium jet system to the detection area.

During the past year we have completed the study of ^{90}Mo whose structure is populated through the beta decay of two isomers, ^{90g}Tc and ^{90m}Tc. The ^{90g}Tc has been determined to have a $J^{\pi}=1^{+}$ and decays with a half-life of (8.7 ± 0.3)s and Q_{EC} = (8.8 ± 0.3) MeV, while the ^{90m}Tc has a probable $J^{\pi}=6^{+}$ or 7^{+} and decays with a half-life of (49.2 ± 0.4)s and a Q_{EC} = (9.3 ± 0.3) MeV. States of the quasi-ground state band up to spin 6^{+} as well as a 5^{-} state in ^{90}Mo have been identified.

The study of the decay of ^{89}Tc is nearly completed. The ^{89}Tc, similar to ^{91,93}Tc, has been found to have two beta decaying isomers, one of which decays with an approximate half-life of 20 s, populating the negative parity low spin states and the other decays with an approximate half-life of 2.2 m, exciting the positive-parity high spin states in ^{89}Mo. Experiments are

*Results presented in this report should not be quoted without specific permission of the investigators.

underway for the measurement of Q_{EC} and the accurate determination of decay half-lives. Tentative level structure which includes states with spin up to $13/2^+$ has been constructed.

A study of the beta decay properties of ^{86}Nb has reached an advanced stage. This nucleus has been found to decay with a half-life of about (80 ± 10)s. It has probably a low spin value because it decays with a strong branch to the 2^+ state in ^{86}Zr, though direct or indirect excitation of the 0^+, 4^+, 5^- and 6^+ states in the latter have also been observed. However, there appear to be several unexplained observations and more measurements are required to sort them out.

Also in progress is a theoretical description of the nuclei in the $N < 50$ region using the interacting boson approximation model through the computer program PHINT. This model has been known to enjoy great success in nuclei heavier than Cs. It would be interesting to investigate its applicability to the lighter-mass nuclear region. However, an extensive search must be performed to find the correct values for the parameters in the model.

2, Rare Earth Nuclei Far From Beta Stability

(J. Deslauriers, S.C. Gujrathi and S.K. Mark)

Over the past few years an intense effort had been made to study the unstable nuclei in the light mass (below Gd) rare earth region. Valuable information has been obtained on the systematic variation of their nuclear structure properties as a function of N and Z. Indeed this project has contributed significantly to the understanding of these nuclei. It has helped to pioneer the first successful application of the interacting boson model in this nuclear region. During the past year, most of the work has been devoted to bringing this project more or less to a conclusion by completing several further measurements on the beta decay of the N=77 isotones ^{140}Eu, ^{139}Sm and ^{138}Pm and the N=76 ^{139}Eu and by synthesizing the data into published form. At present, several publications are in preparation.

3. Delayed Charged Particle Emission

(H. Dautet, S.K. Mark and R. Turcotte)

This project is to study beta delayed charged particle emission in heavy nuclei (A>90). The precursors are to be produced by nuclear reactions induced by the internal beams (p, ^{3}He and ^{4}He) in the cyclotron and then transported to the experimental area by the helium jet transport system. However, the project has encountered several difficult problems. The first major problem we met was the very high flux of positrons resulting from beta decay of nuclei produced unavoidably together with the precursors. To overcome this problem, a magnetic positron filter was constructed and appears to have fulfilled its function when tested with standard sources and this has been reported in the 1979 Progress Report. However, when the filter was put to on-line tests, during the past year, no delayed heavy charged particles were observed. We therefore decided to observe the activity directly with a Si detector telescope. To enable us to do this, a skimmer system for the helium jet was constructed and installed. The skimmer system seemed to work well, with transmission efficiency of about 60%, but we continued to fail to observe heavy delayed particles.

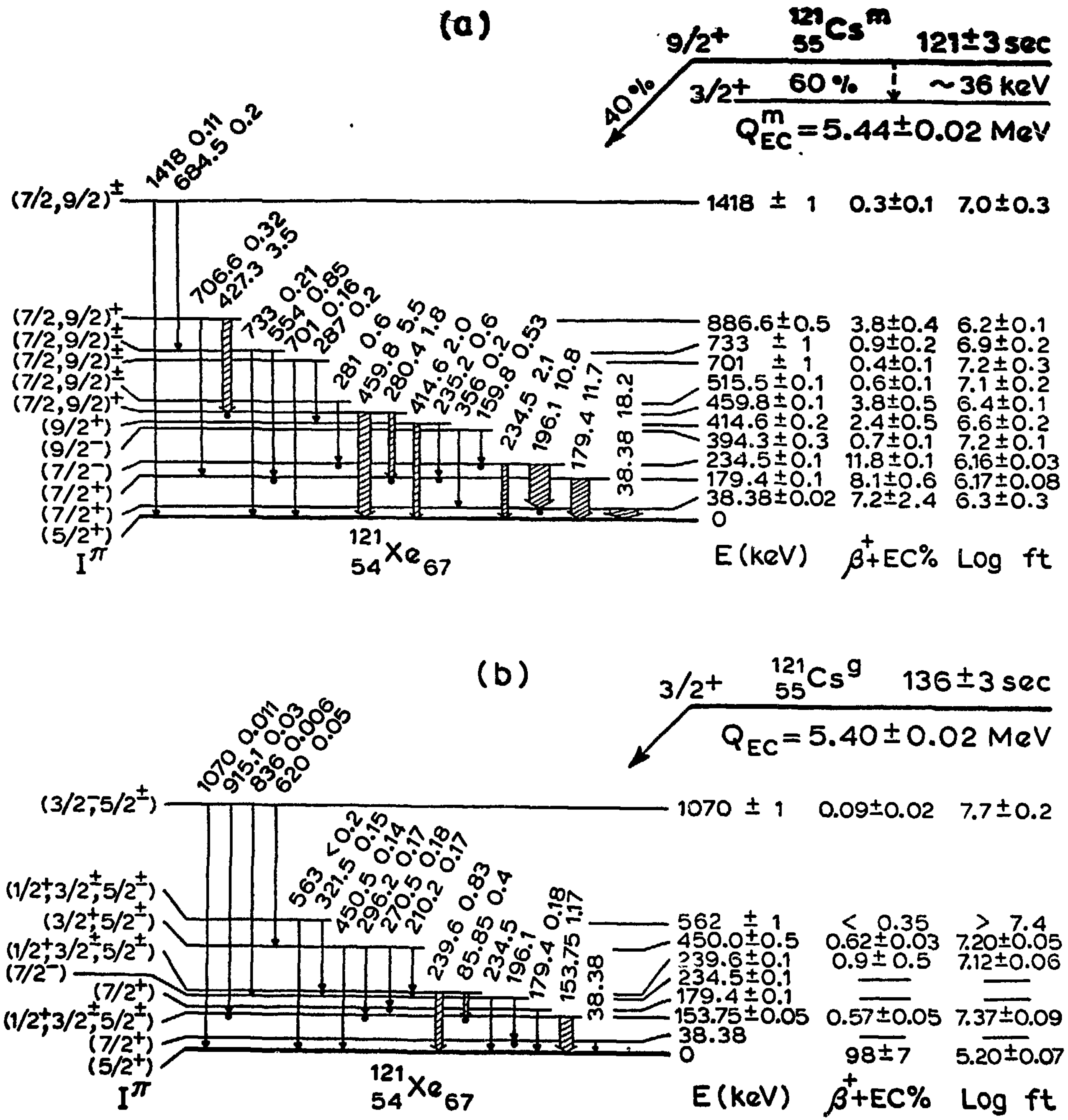
Because of the characteristics of our helium jet system for internal bombardments in the cyclotron, we have to use a relatively high concentration of aerosol particles as recoil carriers in the jet in order to obtain good transport efficiency. These aerosol particles will then form a thick layer of deposition on the source collection spot on a tape. These depositions do not affect β- or γ- spectroscopic measurements, but are detrimental to charged particle detection. In fact, it was observed that for a collection time of 10 seconds, the deposition can be sufficiently thick to stop a 4 MeV alpha particle. Furthermore, the deposition was not uniform, hence, it smears the energy of the emitted particles. It was concluded that the aerosol is unsuitable as recoil carriers for the study of delayed particle emission.

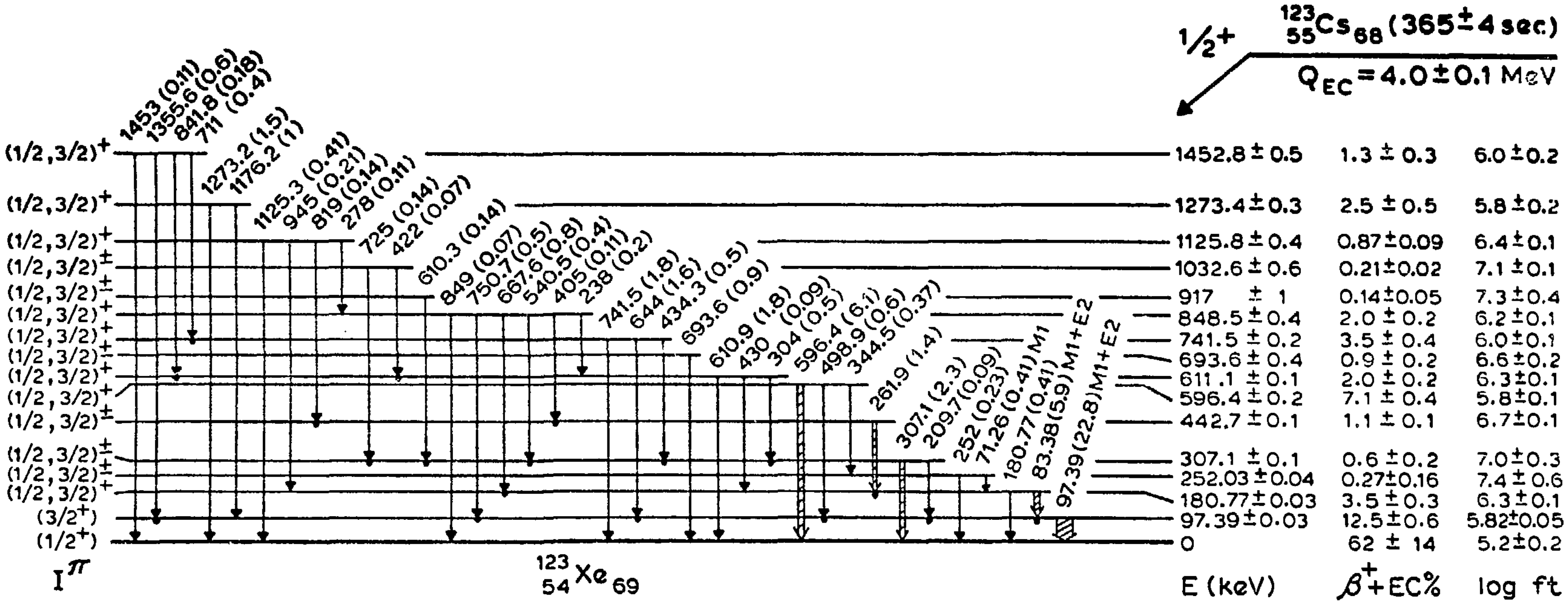
Subsequently, many different types of recoil carriers were investigated. It was found that ethylene offers the next best transportation efficiency after aerosol (about 60% of that of the latter). However, a new problem was encountered with the ethylene carriers; the activities do not stick too well to the collection tape. This may have something to do with the pressure of deposition and/or heating effects on the ethylene due to the beam. At present, several studies of this problem are underway.

4. Structure of $^{121,123}Xe$

(J.E. Crawford, K. Sofia and B.N. Subba Rao)

We have completed the study of the structure of $^{121,123}Xe$ via spectroscopic studies of the decay of $^{121}Cs^{g,m}$ and ^{123}Cs. These isotopes were produced via $^{124}Xe(p,xn)$ reactions. The target material used was xenon gas with ^{124}Xe enriched to 40%, enclosed in beryllium containers. Proton bombardment energies of 52 MeV and 33 MeV were used for the production of $^{121}Cs^{g,m}$ and ^{123}Cs, respectively. Auxiliary experiments with $^{121}Te(\alpha,xn)$ reactions were performed to measure the α_K coefficient of some of the γ-transitions. The decay schemes obtained are shown in the accompanying figures. The low-lying states can be understood in the framework of the Nilsson model with deformation parameter β varying from +0.16 to +0.19.


(a)
9/2+ $^{121}_{55}Cs^{m}$ 121±3 sec
3/2+ 60 % ~36 keV
40%
Q^{m}_{EC}=5.44±0.02 MeV
(7/2,9/2)± 1418 ± 1 0.3±0.1 7.0±0.3
886.6±0.5 3.8±0.4 6.2±0.1
733 ± 1 0.9±0.2 6.9±0.2
701 ± 1 0.4±0.1 7.2±0.3
515.5±0.1 0.6±0.1 7.1±0.2
459.8±0.1 3.8±0.5 6.4±0.1
414.6±0.2 2.4±0.5 6.6±0.2
394.3±0.3 0.7±0.1 7.2±0.1
234.5±0.1 11.8±0.1 6.16±0.03
179.4±0.1 8.1±0.6 6.17±0.08
38.38±0.02 7.2±2.4 6.3±0.3
0
$^{121}_{54}Xe_{67}$
Iπ E(keV) β+EC% Log ft
(b)
3/2+ $^{121}_{55}Cs^{g}$ 136±3 sec
Q_{EC}=5.40±0.02 MeV
(3/2−,5/2±) 1070 ± 1 0.09±0.02 7.7±0.2
562 ± 1 < 0.35 > 7.4
450.0±0.5 0.62±0.03 7.20±0.05
239.6±0.1 0.9±0.5 7.12±0.06
234.5±0.1
179.4±0.1
153.75±0.05 0.57±0.05 7.37±0.09
38.38
0 98±7 5.20±0.07
$^{121}_{54}Xe_{67}$
Iπ E(keV) β+EC% Log ft



1/2+
$^{123}_{55}Cs_{68}$ (365±4 sec)
Q_{EC}=4.0±0.1 MeV
1453 (0.11)
1355.6 (0.6)
841.8 (0.18)
711 (0.4)
1273.2 (1.5)
1176.2 (1)
1125.3 (0.41)
945 (0.21)
819 (0.14)
278 (0.11)
725 (0.14)
422 (0.07)
610.3 (0.14)
849 (0.07)
750.7 (0.5)
667.6 (0.8)
540.5 (0.4)
405 (0.11)
238 (0.2)
741.5 (1.8)
644 (1.6)
434.3 (0.5)
693.6 (0.9)
610.9 (1.8)
430 (0.09)
304 (0.5)
596.4 (6.1)
498.9 (0.6)
344.5 (0.37)
261.9 (1.4)
307.1 (2.3)
209.7 (0.09)
252 (0.23)
71.26 (0.41) M1
180.77 (0.41)
83.38 (5.9) M1+E2
97.39 (22.8) M1+E2
(1/2,3/2)+
(1/2,3/2)+
(1/2,3/2)+
(1/2,3/2)±
(1/2,3/2)±
(1/2,3/2)+
(1/2,3/2)+
(1/2,3/2)±
(1/2,3/2)+
(1/2,3/2)+
(1/2,3/2)±
(1/2,3/2)±
(1/2,3/2)±
(1/2,3/2)+
(3/2+)
(1/2+)
Iπ
$^{123}_{54}Xe_{69}$
1452.8 ± 0.5 | 1.3 ± 0.3 | 6.0 ± 0.2
1273.4 ± 0.3 | 2.5 ± 0.5 | 5.8 ± 0.2
1125.8 ± 0.4 | 0.87 ± 0.09 | 6.4 ± 0.1
1032.6 ± 0.6 | 0.21 ± 0.02 | 7.1 ± 0.1
917 ± 1 | 0.14 ± 0.05 | 7.3 ± 0.4
848.5 ± 0.4 | 2.0 ± 0.2 | 6.2 ± 0.1
741.5 ± 0.2 | 3.5 ± 0.4 | 6.0 ± 0.1
693.6 ± 0.4 | 0.9 ± 0.2 | 6.6 ± 0.2
611.1 ± 0.1 | 2.0 ± 0.2 | 6.3 ± 0.1
596.4 ± 0.2 | 7.1 ± 0.4 | 5.8 ± 0.1
442.7 ± 0.1 | 1.1 ± 0.1 | 6.7 ± 0.1
307.1 ± 0.1 | 0.6 ± 0.2 | 7.0 ± 0.3
252.03 ± 0.04 | 0.27 ± 0.16 | 7.4 ± 0.6
180.77 ± 0.03 | 3.5 ± 0.3 | 6.3 ± 0.1
97.39 ± 0.03 | 12.5 ± 0.6 | 5.82 ± 0.05
0 | 62 ± 14 | 5.2 ± 0.2
E (keV) | β+ + EC% | log ft

5. In-Beam Spectroscopy

(J.E. Crawford, G. Giles, J.E. Kitching, K. Sofia, R. Tacik and B.J. Varley)

(a) Facility Development

Early experiments were hampered by low beam intensity and poor beam stability. With the installation of the radial ion source, however, work has progressed much more rapidly. Improvements of the beam quality through installation of a sextupole magnet at the exit of the cyclotron extraction channel, and realignment of the external beam line to improve beam transmission, particularly for degraded energy beams, have also facilitated our studies.

Early in the year extra shielding (18" of water and concrete) was installed around the target area to reduce background radiation (particularly neutrons originating in the cyclotron and beam switching magnet). A layer of 0.03" aluminum sheet surrounding the detectors and associated electronics was also installed to shield out radiofrequency noise generated by the cyclotron R.F. system.

Gamma ray angular distributions, excitation functions and coincidence measurements are now being routinely performed with this apparatus using time stretched beams of ^{4}He at energies between 50 and 100 MeV.

A gamma ray multiplicity filter, consisting of six NaI detectors and two Ge(Li) detectors has been constructed. Using this device each pair of gamma rays detected in coincidence in the Ge(Li)s can be labelled with the number of NaI detectors which were simultaneously triggered, before being stored on magnetic tape in event-by-event mode in the usual fashion. A simplified version of this device was used in some of the work discussed below and has proved of great value in identifying weak transitions between high lying levels.

(b) Experimental Results

In-beam investigations of the levels of $^{108,110,112}Sn$ via (α,4nγ) reactions on isotopically enriched targets of $^{108,110,112}Cd$ in oxide form have been largely completed. Measurements of gamma ray energies, their intensities, angular distributions and excitation functions, have been made, together with γ-γ coincidence measurements performed both with and without the γ-ray multiplicity filter. Preliminary analysis of the data has been completed. For the case of ^{112}Sn, the previous structure proposed by Bron et al. (Nucl. Phys. A318, 335 (1979)) has been confirmed and extended to higher spins (14^+ or 16^+). For the lighter $^{108,110}Sn$

isotopes, our preliminary results indicated simpler level schemes and the absence of one of the series of strong E2 cascade transitions identified in ^{112}Sn. At present, we are in the process of completing the data analysis and the reason for this change of behaviour will be investigated later.

During the past year, we have also studied ^{141,142}Pm structures via ^{141}Pr(α,xnγ) reactions. Similar measurements as the Sn isotopes were carried out. Data analysis is in progress and some preliminary results indicate strong γ-cascades in the odd-even and odd-odd nuclei near the N=82 shell. Also in progress is the study of high spin states in even Xe isotopes. Here, only preliminary results were obtained and further experimental measurements are needed.

6. Q_β Measurements

(M. Chatterjee, H. Dautet, D. Hetherington, R. Iafigliola, J.K.P. Lee, R.B. Moore, T. Nagarajan, D.M. Rehfield and K. Shahien)

(a) Beta Response Functions

During the past year, we have extended the studies on the beta response functions to two other detector systems, a collimated E detector of 15 mm thick Ge(HP) and a ΔE-E telescope. These studies offer an opportunity to independently check the reliability of the data analysis procedure and the dependence of end-point energies on the particular beta response function used. Also these detectors can be adapted for short-lived isotope decay studies which are not yet possible for the superconducting solenoid beta spectrometer.

As a starting point, the beta response function obtained from a Monte Carlo calculation was used. The response function parameters were adjusted to improve the fit to two standard β^- emitting sources: ^{32}P and ^{88}Rb. Experimental data under various experimental conditions were obtained and their effects on the response function parameters were examined. This analysis procedure is lengthy and tedious. At present, our analysis indicates that the contribution from the uncertainties in response function to the uncertainties in beta end-point-energy determination will be less than 0.3% (or about 15 keV for 5 MeV beta end-point energy). This means that in some decay studies this uncertainty in the response function could be the dominating factor, indicating that these effects should be investigated further if higher precision is required. At present, we are attempting to extract reliable energies and branching ratings for lower energy beta feeding branches. For β^+ decay studies, the situation is more complicated and a similar approach has been adopted.

(b) Experimental Results

The ΔE-E telescope was mounted at the source-collection port of the on-line isotope separator, to study the beta decay of $^{88-95}$Rb and $^{138-144}$Cs and some of their daughters. The telescope consists of a 200 mm^2 x 300 μ thick ΔE-detector and a 500 mm^2 x 15 mm thick Ge(HP) E-detector. The beta response function of such a set-up was studied and the resulting parameters were used to analyse the beta energy spectra for the end-point energies.

The results for $^{88-95}$Rb and $^{138-144}$Cs are in general agreement with those recently published, though in some cases, the interpretation is different for the particular level that these beta transitions are feeding. These different interpretations can only be resolved via more γ-spectroscopic studies. These are planned for the near future. Beta spectra from the decay of the daughters of $^{91-95}$Rb were obtained and are being analysed. These studies were undertaken to determine the masses of the members of the mass chains systematically so that results can be compared to those from direct on-line mass measurements (Phys. Rev. C19, 1504 (1979)).

The decay properties of the daughters of $^{139-144}Cs$ were studied by both the ΔE-E telescope and the superconducting solenoid beta spectrometer. Data are being analysed. It seems that for some isotopes, additional knowledge of decay properties are necessary and they will be studied in the near future.

7. Superconducting Solenoid Beta Spectrometer Development

(A. Al-Alousi, D. Hetherington, J.K.P. Lee, R.B. Moore and D.M. Rehfield)

The construction of the horizontal-bore superconducting-solenoid beta spectrometer has been completed. This spectrometer is presently undergoing tests, and should be ready for serious experimental work in the near future. Preliminary tests of the cryogenic performance of the spectrometer indicate that the use of super-insulation in the construction has resulted in a considerable improvement of the performance of this type of instrument.

The cyrostat design allows a 6 cm diameter, room-temperature bore for the solenoid. A bore magnetic field as high as 7 tesla has been achieved. Together with a 15 mm-depletion-depth, 500 mm^2 surface area Ge(HP) detector, it will permit precise studies of the beta spectra of virtually any beta-decaying nucleus. The collection solid angle for beta rays will be close to 2π steradians, and the large distance achievable between the radioactive source and the detector will ensure that the beta spectra will not be distorted by γ-rays arising from the source.

The initial phase of the work will be the determination of beta response functions under this particular mode of operation. The mechanical design for such a system is under construction and will be completed in the near future. Tape transport will be incorporated for short lived isotope studies.

8. A Search for the Neutrino Rest Mass

(D.M. Rehfield, W.F. Davidson, W. Dixon and J. Storey)

Recent studies of the beta spectrum of ^3H have suggested that this spectrum is distorted by a finite electron anti-neutrino rest mass of about 35 eV. An experiment is underway at the NRC, Ottawa, to attempt to verify this result. A Ge(Li) detector has undergone implantation of ^3H atoms, and an attempt will be made to test the sensitivity of the beta spectrum to the neutrino rest mass. Data-analysis techniques developed in this Laboratory have been modified for the analysis of this type of data, in which the maximum electron kinetic energies are of the order of 18 keV. A study of the detector response function for the experiment is also underway.

9. Nuclear Fission Studies

(P. Beeley, M. Chatterjee, H. Dautet, J.K.P. Lee and L. Yaffe)

We have completed the studies of proton and deuteron induced fission on $^{233,235}U$, using the on-line mass spectrometric method. Relative independent yields of Rb, Cs and In isotopes at different incident energies were obtained. At present, their absolute cross-sections are being measured using radio-chemical methods. Also in progress is the Z=2 particle induced fission yield.

During the past year, we have also studied the Ir(p,f)Rb reactions. The fissioning cross-section of these A≈200 nuclei are small (~few mbs), and the fission barrier is high. The total number of neutrons emitted per symmetric fission was determined from the Rb mass distributions. The yields are about 1.5 neutron more than from similar reactions induced by heavy ions in the same mass region, but are consistent with the prediction of exciton model calculations. These results are consistent with the contention that for heavy ion induced fission, the high intrinsic spin of the fission fragments favour γ-emission over neutron evaporation. A similar study of $^{181}Ta(p,f)$ reaction is in progress. The experiment will be more difficult since the estimated σ_f is one order of magnitude lower.

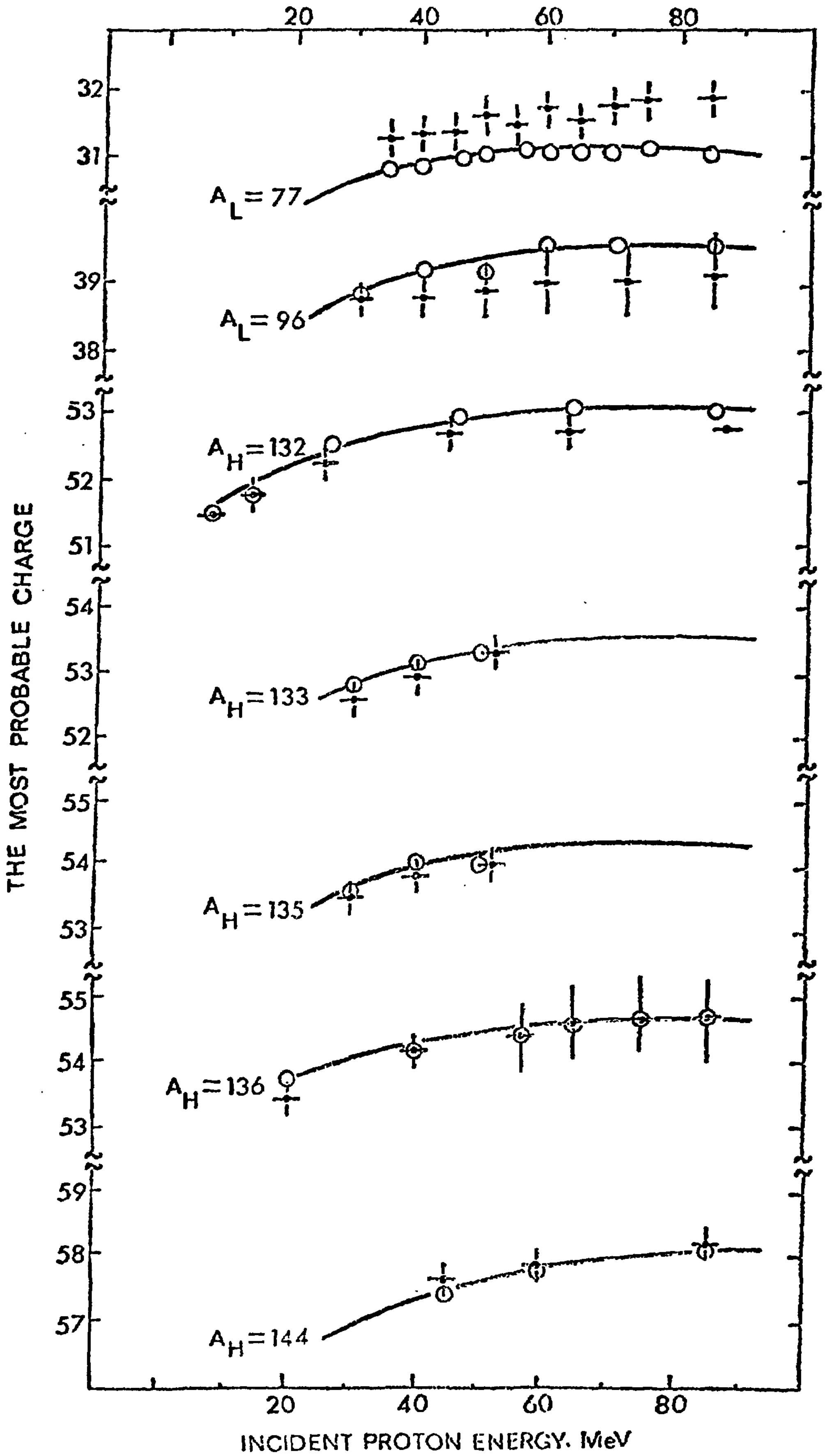
10. Proton and Alpha Induced Nuclear Reactions

(K.I. Burns, C. Chung, J.J. Hogan and E. Gadioli)

During the past few years, we have developed the exciton model of nuclear reactions to include the emission of alpha particle clusters followed by fission. The calculation was successfully applied to the fission-evaporation competition for proton induced reations on ^{232}Th at incident energies up to 100 MeV (Phys. Rev. 20C, 1831 (1979)).

We have noticed a correlation between whether a nucleus fission in symmetric or asymmetric mode and its value of Z^2/A. This idea is in contradiction to the conventional concept where the fissioning mode is related to the excitation energy. We have explored this new correlation, and, using the exciton model calculation, have successfully accounted for the varying percentage of symmetric fission in ^{238}U with increasing incident proton energies. We have also used the exciton model results to calculate the charge dispersion in high energy particle induced fission. A comparison of the calculated and experimental results for the peak in the charge dispersion curves for $^{232}Th(p,f)$ reaction is shown and excellent agreement is obtained. Similar comparisons are being extended to $^{238}U(p,f)$, $^{235}U(n,f)$ and $^{239}Pu(n,f)$ reactions.

We have extended our exciton model to study the alpha particle



20
40
60
80
32
31
$A_L = 77$
39
38
$A_L = 96$
53
52
51
$A_H = 132$
54
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52
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53
$A_H = 135$
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54
53
$A_H = 136$
59
58
57
$A_H = 144$
THE MOST PROBABLE CHARGE
INCIDENT PROTON ENERGY. MeV

induced reactions. By concentrating on the fission cross-section and emission of high energy nucleons in the process, good agreement was obtained between the calculation and data for alpha induced reaction on ^{93}Nb. At present, we are attempting to extend the model to include the break-up mechanism, and additional experimental work is in progress.

11. Positron Emission Tomography for Three Dimensional Mapping of Regional Cerbral Blood Flow and Regional Cerebral Metabolism

(Y.L. Yamamoto, C.J. Thompson, E. Meyer, L. Nikkinen, W.H. Feindel, S.K. Mark and L. Yaffe)

During the past few years, we have developed a double-ring, positron emission tomography (PET) device to monitor the three-dimensional distribution of positron emitting isotopes in the human brain. At present, a spatial resolution of 0.7 cm has been achieved. When ^{77}Kr is used with the bolus inhalation technique, the spatial distribution of the positron emitting ^{77}Kr at successive time intervals can be obtained and the three-dimensional regional cerebral blood flow (rCBF) pattern in the human brain can be deduced. This ^{77}Kr PET method is ideal as a non-invasive technique and gives minimum radiation dose to the patient.

In the past two years, we have applied the ^{77}Kr PET studies to more than 250 patients with cerebrovascular disorders. In these cases, the degree of local cerebral ischemia is obtained in the resting state. Then, the degree of improvement of rCBF in their focal ischemic area as well as topographical pattern changes of rCBF in the cross-section of the brain is examined by a repeat of the ^{77}Kr PET study 15 minutes following 5 percent CO_2 inhalation. Further study is in progress to determine the role of CO_2 in various stages of occlusive cerebrovascular disorders. The effectiveness of medical and surgical treatments in patients with cerebrovascular disorders were also examined. Encouraging results for early diagnosis in patients with vertebro-basilar insufficiency were also obtained. All these studies contributed towards our understanding of pathological processes in cerebrovascular disorders, which will ultimately aid the development of a logical treatment.

We are also planning to expand the PET project to include metabolic research, such as regional glucose metabolism using ^{18}F labelled 2-fluoro-2-deoxyglucose, and regional oxygen consumption rate using ^{15}O to elucidate a basic understanding of pathophysiological mechanism. For these studies, large amounts of activities are required and a compact medical cyclotron has been purchased to produce these as well as ^{11}C and ^{13}N isotopes. The preparation for installation of this cyclotron is in its final stages and should be integrated into our research program by early 1981.

12. Whole Body Nitrogen Content

(R.E. Bell, S. Kovalski, J.K.P. Lee, J. Robson and H. Shizgal)

The nitrogen content of the human body is mostly located in the form of muscle and collagen, and the determination of the total body nitrogen (TBN) provides a quantitative estimate of muscle mass. This information is very useful in such cases as the evaluation of certain treatment method for malnutrition cases, and the recovery from certain major illnesses.

During the summer of 1980, in collaboration with personnel from the nuclear medicine group at the Royal Victoria Hospital (RVH), we started to investigate the method to optimize a set-up for a neutron activation facility using Pu-Be sources. The TBN is to be determined from the intensity of the 10·8 MeV γ-ray from $^{14}N(n,\gamma)^{15}N$ reaction. In August, two 10 mCi Pu-Be sources were provided by RVH, and the neutron energy distributions and intensities for various source moderator and collimator arrangements are being studied. Also, the type of γ-detector and geometrical set-up studies are planned. Other applications of this facility are being investigated.

IV. SCIENTIFIC PUBLICATIONS DURING 1979-80

This list includes articles published in 1979, which did not appear in last year's Annual Report.

A. Publications in Refereed Journals

1. "Fissionability of Nuclides in the Thorium Region at Excitation Energies to 100 MeV", J.J. Hogan, E. Gadioli, E. Gadioli-Erba and C. Chung, Phys. Rev. C19, 1831 (1979).

2. "Positron Emission Tomography: A New Method for Examination of the Circulation and Metabolism of the Brain in Man", Y.L. Yamamoto, C. Thompson, E. Meyer, J. Little and W. Feindel, Adv. in Neurosurgery 7, 3 (1979).

3. "Positron II: A High Efficiency Positron Imaging Device for Dynamic Brain Studies", C.J. Thompson, Y.L. Yamamoto and E. Meyer, IEEE Trans. on Nuc. Sc. NS-26(1), 583 (1979).

4. "Charge Dispersion Studies of Light-Mass Nuclides in the Fission of ^{232}Th by Protons of Energies 35-85 MeV", M. Diksic, J-l. Galinier, H. Marshall and L. Yaffe, J. Inorg. Nucl. Chem. 41, 795 (1979).

5. "Synchrocyclotron Improvements", G. Bavaria, J.E. Crawford and R.B. Moore, IEEE Trans. on Nucl. Sc. NS-26, 2004 (1979).

6. "An Ion Source for Indium and Gallium", L. Nikkinen, B.P. Pathak, L. Lessard and J.K.P. Lee, Nucl. Inst. and Method, 175, 425 (1980).

7. "Decay of ^{100}Ag", H.I. Hayakawa, I. Hyman and J.K.P. Lee, Phys. Rev. C32, 247 (1980).

8. "Decay of ^{94g}Rh and ^{94m}Rh", K. Oxorn, B. Singh and S.K. Mark, Z. Physik A294, 389 (1980).

9. "Independent Yield of Rb, In and Cs Isotopes in the Proton Induced Fission of ^{232}Th", L. Nikkinen, B.P. Pathak, L. Lessard and I.S. Grant, Phys. Rev. C22, 617 (1980).

10. "Fusion Cross-Sections for ^{13}C + ^{13}C at Low Energies", M.L. Chatterjee, L. Potvin and B. Cujec, Nucl. Phys. A333, 273 (1980).

11. "An Evaluation of Alpha Clustering in Heavy Nuclei", J.J. Hogan, Z. fur Physik A295, 169 (1980).

12. "Half-Lives of Neutron Deficient Europium Nuclides", J.J. Hogan, Radiochimica Acte 27, 73 (1980).

13. "Yield of Deep Spallation Products of Medium to Heavy Mass Targets Bomarded with 480 MeV Protons", H. Dautet and B.D. Pate, Can. Jour. of Phys. 58, 891 (1980).

14. "A Comparison of the Statistical Treatment of Results Using Concentration of Elements Determined by Neutron Activation and X-Ray Fluorescence Analysis Methods", J. Radionucl. Chem. 55, 101 (1980).

15. "^{77}Kr Clearance Techniques for Measurement of Regional Cerebral Blood Flow by Positron Emission Tomography", Emission Tomography Book, Ch. 10, ed. by D.E. Kuhl, G. & T. Management Inc., N.Y. Publisher (1980).

16. "A Semi-Empirical Intrinsic Germanium Detector Response for Beta Rays from 4 to 8 MeV", D.M. Rehfield, R.B. Moore and D. Hetherington, (Accepted by Nucl. Inst. & Meth.).

17. "The Beta Decay of ^{78g}Rb", D.M. Rehfield and R.B. Moore, (Accepted by Phys. Rev.).

18. "Deuteron Induced Fission in ^{233}U", N. Mobed, M.L. Chatterjee, P. Beeley and J.K.P. Lee, (Accepted by Can. J. of Phys.).

19. "Positron Emission Tomography for Measurement of Regional Blood Flow", Brain Blood Flow in the 80's, ed. by A. Carney, Raven Press N.Y. Publisher (In press).

B. <u>Papers Presented at Conferences and Symposia</u>

1. "Level Structure of ^{121}Xe", K. Sofia, B.N. Subba Rao and J.E. Crawford, Bull. of Can. Assoc. of Physics 36, 6 (1980).

2. "High Spin States in ^{141}Pm", G. Giles, K.E. Kitching, R. Tacik, B.J. Varley and J.E. Crawford, Bull. of Can. Assoc. of Phys. 36, 45 (1980).

3. "High Spin States in Light Tin Isotopes", R. Tacik, G. Giles, J.E. Crawford, J.E. Kitching and B.J. Varley, Bull. Can. Assoc. of Phys. 36, 45 (1980).

4. "Recent Improvements to the McGill Synchrocyclotron", R.B. Moore, G. Bavaria, J.E. Kitching and B.J. Varley, Eastern Regional Nucl. Phys. Conf., University of Toronto, March 28-29 (1980).

5. "Analysis of Beta Spectra from an Intrinsic Germanium Detector", D. Hetherington, B.J. Varley and J.E. Kitching, Eastern Regional Nucl. Phys. Conf., University of Toronto, March 28-29 (1980).

6. "Evolution of McGill On-Line Mass Spectrometer", J.K.P. Lee, Invited Paper, Bull. of Can. Assoc. of Phys. 36, 15 (1980).

7. "Precise Q-Values for $^{89-93}Rb$", D.M. Rehfield, R.B. Moore and J.K.P. Lee, Bull. Can. Assoc. of Phys. 36, 16 (1980).

8. "Q_β Measurements for Neutron Rich Cesium Isotopes", K. Shahien, M.L. Chatterjee, D. Rehfield and J.K.P. Lee, Eastern Regional Nucl. Phys. Conf., University of Toronto, March 28-29 (1980).

9. "An Interpretation of Symmetric vs. Asymmetric Fission", C. Chung and J.J. Hogan, Proc. International Conf., Nucl. Phys., Berkeley p. 296 (1980).

10. "Physiological Tomography with Positron-Emitting Tracers for Mapping the Brain Circulation", W. Feindel, Y.L. Yamamoto, E. Meyer and C. Thompson, 12th Conference on Cerebral Vascular Disease, Williamsburg, Va. (1980).

11. "Measurement of Blood Flow in the Vertebro-Basilar System", Y.L. Yamamoto, Symp. on Vertibular Neurotology, Kargel, Basel (1980).

C. Theses

"High Spin States in Light Tin Nuclei", R. Tacik, M.Sc. Thesis, 1980.

"Fissionability and Charge Dispersion Studies of Thorium by Proton of Energy to 90 MeV", C. Chung, Ph.D. Thesis, 1980.

"Rare Earth Nuclides Far From Beta Stability", J. Deslauriers, Ph.D. Thesis, 1979.

"On-Line Mass Spectrometric Study of $^{238}U(d,f)$", N. Mobed, M.Sc. Thesis, 1979.

V. PERSONNEL

A. Resident Personnel

1. Academic and Research Staff

LEE, J.K.P.	Associate Professor, Director
BELL, R.E.	Rutherford Professor (on sabbatical leave 1979-80)
CRAWFORD, J.E.	Associate Professor (on sabbatical leave 1980-81)
KITCHING, J.E.	Professor
MARK, S.K.	Professor (on sabbatical leave 1979-80)
MOORE, R.B.	Professor
CHATTERJEE, M.L.	Visiting Scientist from Saha Institute of Nuclear Physics, India (until September 1980)
DAUTET	Research Associate (commenced March 1980)
NAGARAJAN, T.	Visiting Scientist from Madras University Madras, India (commenced September 1980)
REHFIELD, D.M.	Research Associate (commenced December 1979)
SUBBA RAO, B.N.	Research Associate
VARLEY, B.	National Research Associate

2. Professional and Technical Staff

BAVARIA, Dr. G.K.	Professional Associate Accelerator Physicist (resigned September 1980)
BOWDRIDGE, R.	Professional Asisstant, Instrumentation (commenced May 1980)

2. Professional and Technical Staff (cont'd.)

CUSMICH, L.	Professional Assistant, Accelerator (commenced September 1980)
DAVIES, E.	Machinist
DELLE NEVE, M.	Cyclotron Technician
EGYED, J.	Chief Machinist
JORGENSEN, C.	Electronics Technician
KAY, A.	Cyclotron Technician
Kecani, S.	Machinist
KUCHELA, Dr. K.S.	Electronics Supervisor
LALEFF, S.	Administrative Secretary
MILLS, R.H.	Laboratory Superintendent
NIKKINEN, L.	Professional Associate Accelerator Physicist (commenced October 1980)
PAYMANI, R.	Electronics Technician (deceased January 1980)

3. Graduate Students

AL-ALOUSI, A.	M.Sc.
GILES, G.	M.Sc. (completed September 1980)
HETHERINGTON, D.	Ph.D.
IAFIGLIOLA, R.	Ph.D.
KOVALSKI, S.	M.Sc.
OXORN, K.	Ph.D.
RAMSEY, E.	M.Sc.
SERJIEH, A.	M.Sc.
SHAHIEN, K.	M.Sc.

3. Graduate Students (cont'd.)

SOFIA, K.	Ph.D.
TACIK, R.	M.Sc. (completed September 1980)
TURCOTTE, R.	Ph.D.

4. Summer Students

COLLINS, B.

KENNEDY, I.

WEISSKOP, S.

B. Non-Resident Personnel

1. Chemistry Department

YAFFE, L.	Professor and Vice-Principal
HOGAN, J.J.	Associate Professor
DAUTET, D.	Research Associate (commenced October 1980)
ATTAS, M.	Graduate Student
BEELEY, P.	Graduate Student
EDWARDS, J.	Graduate Student
BURNS, K.	Graduate Student
CHUNG, C.	Graduate Student (completed May 1980)

2. Montreal Neurological Institute

FEINDEL, W.	Professor and Director MNI
YAMAMOTO, Y.L.	Associate Professor, Director Neuroisotope Laboratory MNI
DIKSIC, M.	Assistant Professor

2. <u>Montreal Neurological Institute</u> (cont'd.)

THOMPSON, C.	Assistant Professor
NIKKINEN, L.	Research Fellow (resigned October 1980)
MEYER, E.	Research Fellow