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PROGRESS REPORT FOR SOUTH AFRICA

D.W. Mingay
Atomic Energy Corporation of South Africa Limited, Pretoria

and

W.R. McMurray
National Accelerator Centre, Faure

June 1989

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NUCLEAR ENERGY SYSTEMS - ATOMIC ENERGY CORPORATION OF S.A.

The major facilities available are a 3.75 MV pulsed and bunched Van de Graaff accelerator and the SAFARI-1 reactor.

L-subshell ionization cross-section ratios for proton-, deuteron- and alpha-particle bombardment of elements around Z~50

Dr P B Kotzé

L X-ray production cross-sections were measured for thin targets of Pd, Ag, Cd, In, Sn, Sb and Te in the energy range 0.5 - 3.0 MeV for proton-, deuteron- and alpha-particle bombardment. Subshell ionization cross-section ratios as well as emission rate ratios were extracted and compared with PWBA and ECPSSR theories. The discontinuous nature of the $L_{\beta 1,3,4}/L_{\alpha 1,2}$ intensity ratio as a function of atomic number indicated that the L_1-$L_3M_{3,4}$ Coster-Kronig transition becomes energetically forbidden, while the L_1-$L_2M_{3,4}$ one turns out to be allowed around Z~50.

Neutron-fragment angular correlation measurements in ^{252}Cf spontaneous fission.

Dr C B Franklyn

Data has been acquired of neutron-fragment angular correlations as a function of fragment mass division and neutron energy for ^{252}Cf(s.f.). Analysis of the data and comparison with a locally developed Monte Carlo model are in progress.

Thermal neutron capture gamma-ray spectroscopy

Dr C B Franklyn, Dr C Hofmeyr

A re-evaluation of Atomic and Nuclear Data Table listings (Vol 26, pages 511-559 (1981)) of prompt gamma-rays following thermal neutron capture in natural elements is under way.

REPUBLIC OF SOUTH AFRICA

Progress Report to INDC
1989

Compiled by W.R. McMurray

The work reported below was performed at the National Accelerator Centre, FAURE, and related to work done in the year up to June 1988.

The major facilities at this centre are a 6 MV Van de Graaff accelerator, with terminal and post-acceleration bunching, and, a 200 MeV cyclotron facility consisting of a solid pole cyclotron as injector to a separated sector cyclotron.

1. VAN DE GRAAFF ACCELERATOR PROJECTS

1.1 Reactions and Techniques involving fast neutrons

1.1.1 Neutron inelastic cross sections and the level structure of ^{159}Tb, ^{232}Th and ^{238}U

W R McMurray, I J van Heerden*, E Barnard§, D T L Jones and R Carolissen

* University of Western Cape, Bellville
§ Previously Atomic Energy Corporation, Pretoria

The (n,n') and (n,n'γ) reactions provide useful information on the low-lying level structures of heavier nuclei. Our work on ^{159}Tb, ^{232}Th and ^{238}U is awaiting completion. The ^{159}Tb results were reported as an honours project by R Carolissen (UWC).

1.1.2 Nuclear structure studies with (n,d) reactions

K Bharuth-Ram*, W R McMurray, R Naidoo*, D Aschman§ and L Qangule§

* University of Durban-Westville
§ University of Cape Town

Interest in nucleon pick-up reactions has been heightened by recent claims that pick-up reactions display only 60-70% of the total transition strength (1,2). We have previously reported on the $^{90}Zr(n,d)^{89}Y$ reaction (3) and have also obtained results on the $^{27}Al(n,d)^{26}Mg$ and $^{56}Fe(n,d)^{55}Mn$ reactions, all at E_n = 22 MeV. The experimental technique (4) has been further refined. The charged-particle reaction products are detected in a spectrometer consisting of multiwire proportional counters and a plastic scintillator which allows simultaneous accumulation of particle-discriminated energy spectra over an angle range of 80°. New proportional counters have been constructed and the optical coupling of the scintillator has been improved. A study has been made of the source of background counts in the deuteron spectra, and proton and deuteron backgrounds have been considerably reduced.

The $^{27}Al(n,d)^{26}Mg$ reaction yielded four prominent deuteron peaks corresponding to the ground, 1st, 2nd and "5th" excited states of the residual ^{26}Mg nucleus. The 5th state is actually a group of states centred at 4.3 MeV. Deuteron spectra were derived from the event-by-event data in angle-folded mode for reaction angles from 2.5° to 55°. The new data were analysed using the NAC data reduction computer systems. Comparison between experimental and theoretical cross-sections were carried out via the relationship

$$\sigma(\Theta)_{EXP} = 3/2 \; D_o^2 \; C^2 \; S \; \sigma(\Theta)_{DWBA}$$

The DWBA calculations were performed in the local-energy approximation which included corrections for non-locality and finite-range effects of the optical model potentials.

Table 1 compares the deduced spectroscopic factors with model predictions and values obtained by other workers. The C^2S factors obtained from the $^{27}Al(n,d)^{26}Mg$ reaction are seen to be in good agreement with shell model values and with other proton pick-up results.

Additional data has been obtained for the $^{56}Fe(n,d)^{55}Mn$ reaction which is still being processed. A preliminary study of the $^{51}V(n,d)^{50}Ti$ reaction motivated a more careful examination of background spectra resulting from neutron interactions with the proportional counter gases.

Table 1. Table of spectroscopic factors for the $^{27}Al(n,d)$ reaction.

	refs.	g.s.	1.81MeV	2.93MeV	4.3MeV
Shell model	5	0.29	0.75	0.29	1.80
Weak coupling	6	0.33	1.67	-	3.00
Rotational	6	0.33	0.60	-	0.06
Wildenthal	7	0.30	1.05	0.23	2.15
Cujec	8	0.46	0.86	0.29	-
Wagner	9	0.27	0.92	0.19	1.95
Brady	6	0.24	0.72	-	1.87
Present work		0.27	0.88	0.18	1.65

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1.1.3 Deuterated anthracene spectrometer for 5 to 30 MeV neutrons

F D Brooks*, W A Cilliers*, B R S Simpson, F D Smit, M S Allie*, D T L Jones and W R McMurray

* University of Cape Town

The deuterated anthracene spectrometer consists of a deuterated anthracene crystal 10 mm in diameter x 21 mm, with deuterium-to-hydrogen ratio D/H = 99, mounted via a small perspex light pipe on a photomultiplier connected to a special pulse shape discrimination unit. This spectrometer has unique features which arise principally from two factors: firstly, from the prominent forward recoil peak associated with enhanced backscattering of neutrons in D(n,n)D elastic scattering, and secondly, from the direction-dependent scintillation characteristics of deuterated anthracene which are similar to those of natural anthracene (1). These characteristics provide means for enhancing the forward recoil peak relative to other components in the pulse height spectrum and this leads to a spectrometer with a simple line shape, a single peak in the pulse height distribution for each energy group in the incident neutron spectrum (2). The energy resolution has been shown to decrease from about $\Delta E/E$ = 9% at 7 MeV to about 3% at 30 MeV neutron energy compared to the inverse behaviour of neutron time-of-flight measurements which increases from about 2% at 7 MeV to 4% at 30 MeV for a 6 m flight path and timing uncertainty of 1.3 ns (FWHM).

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1.2 Charged-Particle Induced Reactions

1.2.1 The level structure, gamma ray branching and mean lifetimes of states in ^{43}Sc

L D Olivier§, M P Janse van Rensburg+, R E Julies$, S Froneman&, D M van Rooyen, W J Naudé*, J W Koen*, M G van der Merwe+, J A Stander* and W A Richter*

* University of Stellenbosch
§ ESKOM
+ Department of Health
$ University of Western Cape
& UNISA

$(\alpha,p\gamma)$ reactions on ^{40}Ca, ^{52}Cr, ^{19}F, ^{26}Mg, ^{48}Ti and ^{51}V at E_α = 12 MeV have been used to excite levels in ^{43}Sc, ^{55}Mn, ^{22}Ne, ^{29}Al, ^{51}V and ^{54}Cr. Gamma rays were observed in coincidence with associated protons using a multiparameter data acquisition system. The results on ^{43}Sc have been published (1).

Proton-gamma coincidence spectra of the $^{51}V(\alpha,p\gamma)^{54}Cr$ reaction were accummulated. Very good gamma resolution was achieved over a two-week period which makes a consistent analysis of the data possible in the case of this relatively weak reaction.

To complement the experimental work on ^{51}V, shell-model calculations have been carried out to compare the experimental level scheme of ^{51}V (2) as well as the experimental electromagnetic transition strengths (3) with theoretical predictions. In the calculations a new semi-empirical effective interaction is used. The interaction involves a parameterised form of two-body matrix elements based on one-boson exchange potentials (OBEP) fitted to bare G-matrix elements of the Paris potential (4), and employing schematic interaction forms with variable parameters to simulate the core-polarisation terms.

Table 1. Transition strengths in ^{51}V

Initial state		Final state		B(E2)(e^2fm^4)		B(M1)($\mu_N^2 \times 10^{-3}$)	
E_i(keV)	J^π	E_f(keV)	J_f^π	Expt.	Theory	Expt.	Theory
321	$5/2^-$	0	$7/2^-$	164±21	193	5.3±0.3	0.75
929	$3/2^-$	0	$7/2^-$	88±11	78	–	–
929	$3/2^-$	321	$5/2^-$	127±32	134	0.04±0.09	0.20
				or 13±7		or 3.0±0.9	
1608	$11/2^-$	0	$7/2^-$	148±32	83	–	–
1814	$9/2^-$	0	$7/2^-$	30±16	32	0.75±0.70	2.0
1814	$9/2^-$	321	$5/2^-$	30±19	21	–	–
2410	$3/2^-$	0	$7/2^-$	72±38	61	–	–
2410	$3/2^-$	321	$5/2^-$	54^{+100}_{-40}	5	200±60	330
				or > 310		or < 19	
2699	$15/2^-$	1608	$11/2^-$	67±5	49	–	–

In table 1 the predicted and experimental transition strengths are presented. In both cases the theoretical and experimental values show good agreement.

One of us (LDO) is developing a computer program to analyse particle and gamma spectra within the capabilities of a personal computer. The program is in GWBASIC and can be used on any IBM-compatible computer.

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1.2.2 Angular correlation measurements with (α,pγ) reactions

M G van der Merwe+, S Froneman&, L D Olivier§, R E Julies$, W J Naudé*, J W Koen* and J A Stander*

* University of Stellenbosch
§ ESKOM
\+ Department of Health
$ University of Western Cape
& UNISA

Experiments have been carried out to determine mixing ratios of gamma ray transitions in ^{43}Sc, ^{22}Ne and ^{29}Al using (α,pγ) reactions and Method II of Litherland and Ferguson. The results on ^{43}Sc have been published (1). Measurements on ^{29}Al were partly repeated to improve on counting statistics for the weaker transitions.

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1.2.3 Spins of excited states in ^{55}Mn, ^{22}Ne, ^{29}Al, ^{51}V and ^{54}Cr

M P Janse van Rensburg+, D M van Rooyen, L D Olivier§, R E Julies$, S W Steyn§, W J Naudé* and J A Stander*.

* University of Stellenbosch
§ ESKOM
\+ Department of Health
$ University of Western Cape

Limited success is achieved in using Litherland and Ferguson's Method II to determine simultaneously the spins of excited states and the mixing ratios of gamma ray transitions in a particular nucleus. Under more relaxed experimental conditions the measured cross-sections of (α,pγ) reactions at $E_\alpha \simeq 12$ MeV can be compared with Hauser-Feshbach predictions to determine spin values. Upper limits of gamma ray transition strengths are also taken into account in the assignment of spin values.

1.2.4 A feasibility study of the use of the NAC NaI(Tl) Compton suppression shield for high-resolution (p,γ) studies

J P L Reinecke*, J J A Smit* and W R McMurray

* University of Potchefstroom

The NAC Compton suppression detector was designed to provide for a range of different experimental situations (1). Because of the more complex design of the detector and the increase in dead spaces and cladding material, it can not be expected to perform as well as a detector designed specifically for one purpose (2). The aim of this study was to check the effectiveness of the NAC detector for the observation of low-intensity γ-transitions following proton capture.

Output signals from the six photomultiplier tubes on the main NaI(Tl) segments and the two attached to NaI(Tl) plugs are fed into a single preamplifier-amplifier channel. The voltages on the phototubes were adjusted to give equal outputs for the same γ-energy. The summed spectrum gave an energy resolution of about 100 keV (FWHM). The Ge detector with 17% relative efficiency and 2 keV resolution for ^{60}Co γ-rays was connected to a parallel amplifier channel. The bipolar outputs provided timing discriminator signals for coincidence/anti-coincidence events. With 1.5 μs amplifier timing constants the overall timing resolution was about 125 ns (FWHM) and as the random count rate was small no attempt was made to optimise the timing.

Unsuppressed and suppressed spectra were recorded simultaneously through two ADC's using calibration γ-sources. With ^{60}Co the background suppression factor obtained from the ratio of integrated counts between 300 and 1100 keV was 4.3. This compares well with simple systems used at Daresbury (factors of about 3.5) (3) but not so well with a system designed for a single purpose as used at Utrecht (factor of about 11.2) (4).

Spectra were also obtained for the γ-decays from the (p,γ) resonance on ^{25}Mg at E_p = 1714 keV (5). The spectra were obtained from a 14-hour run with 35 μA of protons on a water cooled target. These spectra show a background suppression factor varying from about 8 at 7.5 MeV down to about 3 at 1.5 MeV with no loss of full-energy photopeak yields (within 3%). The average fraction of single and double-escape peak yields in the suppressed spectrum relative to the yields in the unsuppressed spectrum is 0.28 and 0.08 respectively.

The suppression efficiency of the shield depends critically on the detection in the NaI(Tl) shield of low-energy Compton photons. For the data presented here, the NaI(Tl) detector was biased at about 100 keV. A lower bias did not significantly improve the full background suppression factor for ^{60}Co. A reduced bias of 30 keV might have improved the suppression factor close to the photopeaks. It can be assumed that the metal detector cladding separating the segments and plugs of the NAC shield will largely absorb less than 30 keV photons. Some improvement in the background suppression factor could be sought by using an n-type Ge detector (which has a very thin dead layer) and a detector with a larger relative efficiency.

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2. CYCLOTRON FACILITY PROJECTS

2.1 Integral excitation functions for proton-induced reaction on Mn and Ni in the energy range 20 - 200 MeV

G F Steyn, S J Mills and F M Nortier

Integral excitation functions were measured for the production of a variety of radioisotopes in proton-induced reactions on Mn and Ni involving the $1f^{7}/_{2}$ proton shell closure (at Z = 28) in the decay chain. The well-known stacked-foil technique was employed to cover the (lab.) energy range 20 - 200 Mev. Cross-sections were measured for the production of $^{42,43}K$, $^{43,44m,46}Sc$, ^{48}V, $^{48,49,51}Cr$, $^{52,54}Mn$ and ^{52}Fe from Mn, and $^{43,46}Sc$, ^{48}V, $^{48,49,51}Cr$, $^{52,54}Mn$, ^{52}Fe, $^{55,56,57,58}Co$ and $^{56,57}Ni$ from Ni. Corrections for the contributions of precursors were only applied if the precursors were also measured; otherwise the cross-sections are, in principle, cumulative. In general the present results are in resonably good agreement with previous measurements, where these are available.

Theoretical calculations were performed by means of the latest version of the ALICE computer code, ALICE/85/300 (1), and were based on the geometry-dependent hybrid model for the pre-equilibrium emission of neutrons and protons, in combination with the Weisskopf-Ewing evaporation theory for the subsequent equilibrium emission of neutrons, protons, alpha particles and deuterons. In the calculation of the level densities the default value of A/9 was taken for the level-density parameter and, in addition to a pairing-energy shift, a shell-correction shift of the ground state was also introduced. This has previously been found to be essential in the present mass region, around the closure of the $1f^{7}/_{2}$ neutron and/or proton shells (2,3). The pairing and shell-correction shifts were calculated in the code from the corresponding terms in the mass formula of Meyers and Swiatecki, and were applied back-shifted.

As has also previously been shown by Michel et al. (5), the agreement between theory and experiment was found to vary from excellent to very poor. In some cases, e.g. those of ^{46}Sc, ^{42}K and ^{43}K, the ability of the theory to describe the measured cross-sections by a priori calculations is truly remarkable, taking into account the number of nucleons which are emitted from the compound nucleus to produce these nuclei. In other cases, e.g. those of ^{48}Cr and ^{49}Cr, the complete failure of the model to describe much simpler decay cascades (although the shape is often still predicted reasonably accurately), cannot be explained satisfactorily. Attempts at using other prescriptions (6,7) for applying the calculated pairing corrections have failed to improve the overall agreement with the experimental results, although some improvement could be obtained for certain individual cases.

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