International Atomic Energy Agency

INDC(SAF)-009/G

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

PROGRESS REPORT FOR THE PERIOD 1985/1986

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Atomic Energy Corporation of South Africa Limited

June 1987

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

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Reproduced by the IAEA in Austria
June 1987

87-02904

REPUBLIC OF SOUTH AFRICA

Progress Report to INDC
1987

Compiled by E Barnard

1 National Accelerator Centre - Council for Scientific and Industrial Research

The major facilities at this centre are a 200 MeV separated sector cyclotron using a solid pole cyclotron as injector and a 6 MV pulsed Van de Graaff accelerator with terminal and post acceleration bunching. The work reported in this document was performed on the Van de Graaff accelerator.

1.1 Reactions involving neutrons

1.1.1 Level Structure of ^{159}Tb

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In terms of the Nilsson model most low-lying levels of a distorted odd-A nucleus such as ^{159}Tb can be understood as single-particle states with rotational bands built onto them. Mixing of states belonging to different oscillator shells can also occur. Previous (n,n'γ) measurements carried out at the NAC Van de Graaff (Faure) and the AEC Van de Graaff (Pelindaba) in an effort to obtain a complete decay scheme of ^{159}Tb, had some unresolved normalisation problems and inconsistencies.

In a recent set of measurements at Faure at E_n 0,5 to 1,5 MeV, both ^{7}Li and ^{56}Fe samples were used to minimise the normalisation uncertainties previously encountered. As before, pulsed beam gating techniques were used to discriminate against n-induced backgrounds in a germanium detector placed at the reaction angle of 125°. The high-resolution γ-spectra thus obtained have been analysed for absolute inelastic scattering cross sections.

The new set of excitation curves appear to be self-consistent and should clarify the energy-level scheme previously deduced. We are planning to describe the cross sections in terms of the optical-statistical model and the level parameters.

1.1.2 Polarization in n-p elastic scattering at 21,6 MeV

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The analysing power in n-p elastic scattering have been studied using the anthracene scintillation polarimeter as outlined in the 1984 Annual Report, item 10.1.5 [1] .

The results of a number of measurements made at E_n = 21, 6 MeV are being finalised so that a combined result of analysing power values at centre-of-mass scattering angles can be made available for publication. Analysis of a subset of the data has produced the following set of polarization values:

θ_n^{cm}	P_{np}
90°	0,048 ± 0,0045
110°	0,031 ± 0,004
130°	0,025 ± 0,009
150°	0,010 ± 0,013

The final values will be compared with the Paris potential predictions. These predictions are at present being computed by the theoretical group of the National Physical Research Laboratory of the CSIR.

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1 National Accelerator Centre Annual Report NAC/AR/84-01 (CSIR 1984) p.165

In an attempt at reducing the background correction due to escape events, a measurement was performed to investigate the detection of recoil protons escaping from a small anthracene scintillation crystal when bombarded by 22 MeV neutrons. A plastic scintillator was directly coupled to the end of the cylindrical shaped crystal. The plastic scintillator has a different time response to that of the crystal which results in the PSD pulse of the escaping proton being smaller than that of the non-escaping events. This leads to a cleaner spectrum with most of the escape events being separated from the main body of data. An optimised design, possibly in conjunction with a thin wafer-like crystal, is envisaged for future work on polarization measurements using the scintillation crystal polarimeter. This arrangement will reduce the difficulties presently encountered during analysis of the asymmetry data.

1.1.3 Photodisintegration of the deuteron near threshold

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Analysis of the angular distribution data of photoneutrons from the $^{2}H(\gamma,n)^{1}H$ reaction at six angles between 30° and 135° for E_γ = 2,75 MeV has now been completed.

The data were gathered in three separate series of runs. The weighted means of these data were fitted to $\sigma(\theta) = (a + b\sin^2\theta)$ and the a/b ratio determined. This fit gave a/b = 1,93 ± 0,015 from which σ_m/σ_e = 0,29 ± 0,021 was calculated.

These results agree with other published measurements at this energy with the exception of the measurement of Bishop et al. [1] which has the smallest standard deviation of previous measurements.

The present measurements also agree with theoretical calculations [2], which predict an enhancement in the total cross section due to the explicit inclusion of meson exchange current and isobar configuration effects, unlike the Bishop measurements which do not.

References

1 C R Bishop, L E Beghian and H Halban, Phys. Rev. 83 (1951) 1052

2 H Arenhovel, W Fabian and H C Miller, Phys. Lett. 52B (1974) 303, and H C Miller and H Arenhovel, private communication (1986)

1.1.4 Preliminary investigation of neutorn-proton radiative capture at E_n = 21,7 MeV

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Recent studies, theoretical and experimental, of deuteron photodisintegration and its inverse n-p radiative capture, have revealed that this basic nuclear system is still poorly understood [1]. The energy region 10-200 MeV is regarded as particularly favourable for these studies. An exploratory experiment has been performed at 21,7 MeV using ^{3}H(d,n) neutrons obtained from the NAC Van de Graaff accelerator.

With a cross section 10^4 times smaller than that for neutron elastic scattering, the measurement of n-p radiative capture presents challenging difficulties. To identify the capture reaction against this high background, we have developed a new technique based on refined pulse shape discrimination with a liquid scintillator used as proton target. The 21,7 MeV neutrons selected by time-of-flight gating were incident on a 5 cm diam by 5 cm deep NE 213 liquid scintillator. A radiative (n-p) capture event is indicated by a fast coincidence (10 ns) between the ~11 MeV recoil deuteron in the scintillator and a corresponding ~13 MeV gamma-ray detected in one of the NaI(Tl) detectors placed at suitable angles to the incoming neutron beam. Five parameters were stored on buffer tape for each accepted event: (1)-(3) pulse heights from the scintillator detectors; (4) the Ne 213 pulse shape signal; and (5) the time output for the NaI coincidence measurements.

Off-line analysis of the data showed that the n-p capture events could be clearly identified. Peaks corresponding to n-p capture events are clearly separated from remaining background events. Unfortunately, the event-rate is too low for statistically significant measurements at this energy. However, we plan to use these techniques in measurements at higher neutron energies using neutrons generated by the NAC cyclotron facility.

Reference

1 J M Cameron, S. Afr. J. Phys. (to be published)

1.1.5 A study of the $^{90}Zr(n,d)^{89}Y$ reaction at 22 MeV

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The angular distribution of deuterons from the reaction $^{90}Zr(n,d)^{89}Y$ has been studied at E_n = 22 MeV using a spectrometer that permitted the simultaneous accumulation of data over an angular range of 80°. The spectrometer [1] consists of three multi-wire proportional counters followed by a plastic scintillator. The target in the form of a 15 mg/cm² foil is sandwiched between the first two proportional counters, the first of which acts in anti-coincidence mode. The other two proportional counters act as two "ΔE" detectors, and the scintillator as an energy "E" detector, thus providing Δ E-E particle identification. The energy information from the scintillator is obtained by summing the outputs A and B from the two photomultipliers at the two ends of the scintillator, and the angle information from the empirical ratio (A-B)/(A+B).

The deuteron spectra show two prominent peaks corresponding to transitions to the ground state and to 1,6 MeV excitation in ^{89}Y. The measured angular distributions were compared with DWBA calculations in which the ^{90}Zr ground state was taken to be [2]:

$$\psi(0) = a\psi(p_{1/2})^2 - b\psi(g_{9/2})^2;$$

where $a^2 = 0{,}72$ and $b^2 = 0{,}28$.

The spectroscopic factors deduced from a preliminary analysis of the data are listed in table 1.

Table 1. Spectroscopic factors (C^2S) for the $^{90}Zr(n,d)^{89}Y$ reaction

Ex(MeV)	J^π	(C^2S)
0	$1/2^-$	$1,8 \pm 0,4$
1,51	$3/2^-$	$1,5 \pm 0,4$
1,76	$5/2^-$	$0,7 \pm 0,3$

References

1 W R McMurray and K Bharuth-Ram, S. Afr. J. Phys. 8 (1985) 22

2 A Adams, D Adam, O Bersillon and S Joly, Nuovo Cimento 33 (1976) 171

1.2 Reactions Induced by α-Particles

1.2.1 Elastic scattering of α-particles from ^{28}Si

J J Lawrie, D M Whittal, A A Cowley, S J Mills and W R McMurray

As described previously [1] , the investigation of $\alpha + ^{28}Si$ between 5 and 12 MeV was stimulated by a theoretical prediction [2] which suggested that molecular resonances similar to those observed in $\alpha + ^{40}Ca$ at low energies [3] should be encountered in that energy region.

In an attempt to extract details of possible non-statistical resonances from the experimental data, an analysis which is in principle equivalent to that of ref [3] was exploited. Consequently, it was also assumed that the resonant mechanism is coherent with an underlying optical potential elastic scattering contribution. The compound nuclear mechanism was taken to be incoherent with the direct components. These compound nuclear cross sections were determined by means of Hauser-Feshbach calculations scaled to the experimental values at off-resonance energies between 5 and 6 MeV. For these

calculations, as well as the background part of the direct mechanism, appropriate optical model parameters from the literature [4] were used. The presence of a possible resonance similar to that observed in $\alpha + {}^{40}Ca$ requires that inclusion of the resonant contribution with appropriate parameters in the calculated angular distributions gives good agreement with the experimental quantities.

Comparison of the theoretical and experimental angular distributions near the fluctuation at 6 MeV (c.m.) observed in the excitation function suggests the presence of a resonance in this energy region which is consistent with an angular momentum value of $J = 3$. However, the excellent agreement between theoretical and experimental angular distributions found for this resonance could not be reproduced for any of the other fluctuations in the excitation functions. This suggests that the fluctuations observed for the reaction $\alpha + {}^{28}Si$ may not be comparable to those of $\alpha + {}^{40}Ca$.

Although the experimental conditions such as target-thickness and energy-step size have been carefully selected to facilitate a comparison between ^{28}Si and ^{40}Ca as targets, we have been unable to establish the theoretically expected similarity.

Reference

1 National Accelerator Centre Annual Report NAC/AR/85-01 (CSIR, 1985) p 184

2 K Langanke, R Stademann and D Frekers, Phys. Rev. C29 (1984) 40

3 D Frekers, R Santo and K Langanke, Nucl. Phys. A394 (1983) 189

4 W Wuhr, A Hoffmann and G Philipp, Z. Phys. 269 (1974) 365

1.2.2 The level structure, gamma-ray branching and mean lifetimes of states in ^{43}Sc, ^{55}Mn, ^{22}Ne and ^{29}Al

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* University of STellenbosch

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The (α,p) reactions on ^{40}Ca, ^{52}Cr, ^{19}F and ^{26}Mg were used at E_α = 12 MeV to populate states in ^{43}Sc, ^{55}Mn, ^{22}Ne and ^{29}Al. Gamma-rays were observed in coincidence with associated protons using an on-line data acquisition system. Results for ^{43}Sc are discussed in the Ph.D thesis of S Froneman. The analysis of ^{55}Mn has also been completed.

1.2.3 Angular correlation measurements using (α,p) reactions leading to ^{43}Sc, ^{51}V, ^{22}Ne and ^{29}Al levels

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Mixing ratios of gamma-ray transitions in ^{43}Sc, ^{51}V, ^{22}Ne and ^{29}Al using $(\alpha,p\gamma)$ reactions with Method II of Litherland and Ferguson, have been determined. Results for γ-ray transitions in ^{43}Sc have been reported [1]. A paper describing the work on ^{51}V has been accepted for publication [2].

References

1 National Accelerator Centre Annual Report NAC/AR/85-01 (CSIR, 1985) p 180-181

2 M G van der Merwe, J A Stander, W J Naudé, J W Koen and W A Richter, S. Afr. J. Phys. (in press)

1.2.4 Spins of excited states in ^{43}Sc, ^{55}Mn and ^{51}V and shell-model predictions for ^{43}Sc

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Using the results of the angular correlation study (section 1.2.3 of this report) spin possibilities were obtained for the five energy levels at 3569, 3614, 3631, 3664 and 3683 keV in ^{51}V where this property has not previously been determined. In addition, a spin assingment was made for the 3215 keV level.

For ^{43}Sc and ^{55}Mn nuclei, spins of their excited states were determined by comparing (α,p) and $(\alpha,p\gamma)$ cross sections at E_α = 12 MeV with Hauser-Feshbach predictions while also taking the upper limits of gamma transition strengths into account. For ^{43}Sc, spin possibilities obtained from the angular correlation study of section 1.2.3 were also considered.

Shell-model calculations complementary to the experimental work on ^{43}Sc were carried out on one of the NAC computers, using the new Oxford-Buenos Aires Shell-Model Code (OXBASH) of W D M Rae, N S Godwin, A Etchegoyen and B A Brown. Because a reliable empirical two-body interaction is lacking in the Of-1p shell, the approach of McGrory [1] was adopted in employing a realistic two-body interaction (Kuo-Brown [2]) and renormalising some of the most important matrix elements empirically by substituting values obtained from fits [3] to experimental data. Sixteen matrix elements involving the $0f_{7/2}$ and $1p_{3/2}$ subshells were treated in this way.

The energy level spectrum obtained from a full f-p shell calculation was a slight improvement over that of McGrory, but could of course not predict those experimental states expected to contain large admixtures of 5p-2h configurations [4] . For each calculated state up to 3,5 MeV excitation an experimental counterpart could be identified. Of the four strongest E2 transitions between negative parity states, three were well reproduced with effective charges of e_p = 1,4 e and e_n = 0,6 e, as were the ground state magnetic moment and electric quadrupole moment.

For the positive parity states preliminary calculations were done with $(0d_{3/2}\ 1s_{1/2})^{-1}\ (0f_{7/2}\ 1p_{3/2})$ configurations, again with the empirical values for the dominant $(0f_{7/2},\ 1p_{3/2})$ matrix elements and Kuo-Brown values for the remainder. Although a reasonably good reproduction of the positive parity spectrum was obtained, very large effective charges (e_p, $e_n \sim 3$-4) were required to obtain agreement with the experimental B(E2) values. These unrealistic values probably reflect truncation effects and suggest that the model space should be extended to incorporate excitations involving the $0d_{5/2}$, $0f_{5/2}$ and $1p_{1/2}$ subshell. Further calculations along these lines are envisaged with the new programme and we hope that spurious effects can be eliminated in the larger basis. The largest (J,T) dimensions for the $T = \frac{1}{2}$ states are $4308(3/2^+)$, $5558(5/2^+)$, $5982(7/2^+)$, $5663(9/2^+)$ and $4808(11/2^+)$.

Similarly, admixing 5p-2h configurations (albeit with some truncation) into the negative parity states will show whether large basis shell-model calculations can reproduce the low-lying negative parity states not yet accounted for.

References

1 J B McGrory, Phys. Rev. C8 (1973) 693

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and T T S Kuo and G E Brown, Nucl. Phys. A114 (1968) 241

3 T H Olsen and E Osnes, Physica Norvegica 8 (1975)

4 I P Johnstone and G L Payne, Nucl. Phys. A124 (1969) 217

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Facilities available for physics research are a research reactor SAFARI-1 and a pulsed 3.75 MV Van de Graaff accelerator with terminal bunching.

2.1 Neutron-fragment angular correlation measurements in thermal-neutron-induced and spontaneous fission

In studying the physics of the fission process, both neutron-induced and spontaneous fission studies are undertaken in environments such that direct comparisons of the fission phenomena in different fissioning nuclei can be made. These phenomena include angular correlations between fission fragments, neutrons and gamma-rays. Data has so far been acquired of neutron-fragment angular correlations as a function of fragment mass and neutron energy in $^{235}U(n_{th},f)$ and is still in progress for ^{252}Cf spontaneous fission. Analysis of the uranium data and development of a theoretical model of the fission process indicate that a 20 % scission component is essential to describe some of the observed phenomena. In this analysis a further anisotropic neutron emission component improves the comparisons between the simulated and experimental data. Further analysis incorporating the results for ^{252}Cf (s.f.) are in progress.