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Progress Report to the INDC

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of South Africa (Pty) Ltd.

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Compiled by E Barnard

1.   **Physics Division, Nuclear Development Corporation of South Africa, Pelindaba, Transvaal**

The major facilities used for physics research are a research reactor Safari I and the pulsed 3.75 MV Van de Graaff accelerator with terminal bunching and an on-line computer.

1.1   **Scattering of fast neutrons**

    - E Barnard   C Dednam   D Mingay

Results from $(n,n'\gamma)$ measurements on Ag, Au and Nb have not been fully processed. Some exploratory $(n,n'\gamma)$ studies were performed on natural Ta.   Due to the very large number of levels at low energies threshold measurements were not very meaningful.   A recently developed computer program[1] for establishing energy level diagrams from measured gamma ray decay data hopefully will speed up data processing in order to bring these projects to a successful conclusion.

As part of the study of the level schemes of the two stable Ag isotopes β-decay measurements were performed on ^{109}Pd and ^{107}Cd. These results indicated that for ^{109}Ag two levels (697 keV and 811 keV) and six gamma rays (114, 402, 500, 790, 564 and 609) should be removed from the level scheme previously published[2]. These "gamma rays" were either sum peaks or background.   The 868 keV gamma ray was also found to be due to background. The β-decay half-life for ^{109g}Pd was found to be 13.45 ± 0.02 h. These results have been submitted for publication[3].   In the ^{107}Ag study the new level found by Paradellis et al[4] was confirmed and the half-life for β-decay of ^{107g}Cd was found to be 6.49 ± 0.03 h.

1.   C Franklyn: GRAP, Gamma Ray Allocation Program. To be published as PEL Report.
2.   F El Bedewi, Z Miligy and H Hanafi, Acta Phys. Acad. Sci. Hung. 38 (1975) 153
3.   C Dednam and D W Mingay. Level structure of ^{109}Ag from studies of the decay of ^{109g}Pd. S. Afr. J. Phys. 5 No 4 (1982) 100
4.   T Paradellis, C A Kalfas, Z. Phys. 271 (1974) 79

1.2   (p,n) reactions

- E Barnard and D Mingay

The results from the study of ^{85,87}Sr by means of the ^{85,87}Rb$(p,n\gamma)^{85\ 87}$Sr reaction as well as from the decay of ^{85}Y obtained from the ^{84}Sr(p,γ) reaction, have not been fully processed.   An appreciable number of new gamma transitions were observed. Additional measurements might be necessary.

1.3   Neutron Capture Reactions

- C Hofmeyr and C B Franklyn

During the period under review the main activity centred around developing and implementing an interactive computer program to facilitate the building of a consistent decay scheme from transition energies and intensities between levels. The degree of uniqueness obtained is naturally a strong function of the number of transitions and their accuracy. The program is at present being applied to accurate gamma-ray data on ^{74}Ge obtained at ILL, Grenoble by means of Du Mond type crystal spectrometers and a pair spectrometer. Collaborative work on ^{28}Al[1] and ^{36}Cl[2] done at ILL, Grenoble, has been publsihed. The neutron binding energies of ^{195}Pt and ^{196}Pt were evaluated[3].

At the SAFARI-1 reactor Rb(n,γ) measurements have been resumed with a pair spectrometer.

β-decay half-lives after neutron capture in ^{232}Th were measured anew by means of gamma-ray spectroscopy.

1.   H H Schmidt, P Hungerford, H Daniel and T von Egidy (Physik Department, T U München), S A Kerr, R Brissot, G Barreau, H G Börner and C Hofmeyr (Institut Laue-Langevin, Grenoble) and K P Lieb (Univ Göttingen). Levels and gamma energies of ^{28}Al studied by thermal neutron capture, Phys. Rev. C25 (1982) 2888

2.   B Krusche and K P Lieb (II Physikalisches Institut, Univ Göttingen) H Daniel and T von Egidy (Physik Department, T U München), G Barreau, H G Börner, R Brissot and C Hofmeyr (ILL, Grenoble) and R Rascher (Univ zu Köln).   Gamma ray energies and ^{36}Cl level scheme from the reaction ^{35}Cl(n,γ), Nucl. Phys. A386 (1982) 245

3.   C Hofmeyr, PEL 280 (1982)

1.4 Characteristic gamma-ray facility

- C Hofmeyr

A vertical gamma-ray beam facility for studying photon scattering and photo=
nuclear reactions utilizes an exchangeable primary sample, e.g. nickel, backed
by a graphite thermal pile next to the reactor core, to generate characteristic
gamma rays by neutron capture. With a nickel sample the main beam component is
9.0 MeV gamma rays. In this facility the secondary sample position, collimation
and background conditions have been revised to improve the yield and signal to
background ratio, since photonuclear cross sections tend to be small.

1.5 Fission studies

- C B Franklyn and C Hofmeyr

As a sequel to earlier neutron correlation studies the investigation of fission
dynamics is being expanded to correlation studies between fission neutrons and
fission products. The apparatus consists of a vacuum chamber for the fission
foil, fission fragment and neutron detectors and multiparameter data acquisition
facilities (up to eight parameters simultaneously). It is primarily a thermal-
neutron beam experiment at SAFARI-1, but can be used for spontaneous fission
studies as well.

2. Southern Universities Nuclear Institute, Faure, Cape Province

The major research facility is a 5.5 MV pulsed Van de Graaff accelerator.
The research program covered a wide variety of topics in basic and applied
science, of which the most relevant are listed below.

2.1 Neutron reaction studies

2.1.1 Level structure and cross section studies using (n,n'γ)

- W R McMurray, M J Renan, I J van Heerden*

^{89}Y

The inelastic scattering cross sections derived from (n,n'γ) measurements[1] are
being compared with neutron time-of-flight measurements by A Smith et al, at
Argonne[2] with a view to joint publication. Consistently lower cross section
values obtained from the (n,n'γ) study will require a re-evaluation and check of
the absolute   normalisation of the SUNI data.

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^{115}In

A similar joint approach together with A Smith of Argonne is also being negotia=
ted. There are obvious advantages to a double approach which combines the high
resolution details derived from the gamma studies[3] with the direct and unambigu=
ous cross sections observed with neutron time-of-flight[2].

^{159}Tb

The data obtained from the (n,n'γ) investigation of the levels and inelastic
scattering cross sections for this nucleus[4] are being prepared for publication.

1.   Item 1.1.2, SUNI Annual Research Report 1980
2.   A Smith, private communication
3.   Item 1.1.3, SUNI Annual Research Report 1980
4.   Item 1.1.4, SUNI Annual Research Report 1980

2.1.2 Photodisintegration of the deuteron near threshold

- F D Smit, F D Brooks, W A Cilliers, W R McMurray, D T L Jones*

The photodisintegration of the deuteron close to threshold (2.226 MeV) is being
investigated using 2.313 MeV gamma-rays from the ^{14}N(p,p'γ) reaction. The
aim is to measure the angular distribution of the photoneutrons which, in turn,
will be analysed to determine the photomagnetic and photoelectric disintegration
amplitudes as outlined previously[1].

The low values of the cross sections being studied make this experiment very
difficult and in particular demand that care be taken to achieve an acceptable
signal-to-background ratio in the neutron detector. Several improvements have
been effected in this area although it is not yet clear whether they will
be sufficient to ensure that the experiment can be completed. The main
improvements include a change from the original NE311 scintillator to an NE321
scintillator in the boron-loaded detector and a change of the entrance window
of the nitrogen gas target (for the gamma-source) from tantalum to platinum.
The pulse-shape discrimination of the NE321 scintillator is markedly superior
to that of NE311 and the change of target window considerably reduces the
neutron background originating from this source. These modifications,
together with the introduction of ring geometry in the experiment, have
achieved a considerable improvement in the signal-to-background ratio.

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* National Accelerator Centre, Faure

A different method is under consideration for extending this experiment to the slightly higher photon energy of 2.615 MeV. The plan is to use gamma-rays of this energy from a ^{228}Th source and to detect photoprotons from photodisinte= gration in a deuterated anthracene crystal. The photoprotons will be detected within the crystal and the anisotropic scintillation property of the crystal[2] will be used to determine their directions and hence the proton angular distri= bution. Tests carried out on the scintillation crystal using 200 keV neutrons suggest that the technique is feasible.

1.   Item 1.1.6, SUNI Annual Research Report, 1980
2.   F D Brooks, Nucl. Instr. and Meth. <u>162</u> (1979) 477

2.1.3 <u>Polarization in n-p and n-d scattering at E$_n$ 23 MeV</u>

- B R S Simpson, F D Brooks, D T L Jones*, I J van Heerden**

The analysis of data from the n-p and n-d polarization experiments at 16.4 and 21.7 MeV, using scintillation crystal polarimeters[1], is not yet complete. The analysis is being held back in order to perfect the computing routines which have been developed to detect and correct small residual systematic asymmetries in the raw data. The routines are tested against computer-simulated experimental data which may incorporate simulated systematic and/or random errors. The correction procedures operate satisfactorily when only the systematic error is present in the simulated data but not when both types of error are present simultaneously. The problem is being investigated and it should be possible to continue with the reduction of the real polarization data as soon as it is solved.

In the interim, some further n-p and n-d polarization experiments have been initiated at 16.4 and 21.7 MeV, using conventional double scattering geometry incorporating a vertex detector together with side detectors to detect the scattered neutrons. These measurements are intended to complement those taken with the crystal polarimeter or to provide additional independent data at scattering angles which are currently of particular interest. These measure= ments show that backgrounds can be reduced to the level required to make accurate polarization measurements. However, running times of several weeks will be necessary in order to achieve the statistical precision required in the polarization measurements.

1.   Item 1.1.7, SUNI Annual Research Report (1980).

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2.1.4 Energy correlations of neutrons from ^{252}Cf spontaneous fission

- D M Whittal, F D Brooks

A study is in progress[1] which tests for the presence of a correlation (or anticorrelation) between the energies of neutrons emitted from a common fission fragment in the spontaneous fission of ^{252}Cf. A comparison is made between the energies of coincident neutrons emitted: (a) at an angle of 30° to one another; and (b) at an angle of 180° to one another, in the laboratory frame. The translational motion of the emitting fragments ensures that these two geometries select predominantly: (a) two neutrons from one of the fragments only (at 30°); or (b) one neutron from each fragment (at 180°). The fragments themselves are not detected in the experiment.

The energies of the fission neutrons were determined by time-of-flight, with gamma-rays detected in a thin plastic scintillator placed close to the ^{252}Cf source to signal the time of the fission. Neutrons at the two angles were detected in Ne213 liquid scintillators equipped with pulse shape discriminators. In order to simplify the analysis, the energy measurements were analysed in terms of the frequency distribution of the ratio $R = E_{lo}/(E_{lo} + E_{hi})$, where R_{lo} and R_{hi} are the lower and higher energies respectively for a coincident neutron pair. The ratios R_1 and R_2 are thus defined for geometries (a) and (b) respectively. In order to test for possible spatial asymmetries in the measurements or analyses, additional ratios R_1' and R_2' are also calculated in which each neutron is paired successively with the non-coincidental neutrons in the data set for the same geometry. Since a very large number of such combinations exist the distributions of the 'scrambled' (or random) ratios R_1' and R_2' are determined with much higher statistical accuracy than those of the real or true ratios, R_1 and R_2.

The results show a close similarity between the distributions of R_1' and R_2' which confirms the absence of any detectable asymmetry which can be attributed to the equipment or the analysis. There is also no significant difference between the distributions of the true ratios R_1 and R_2 observed in geometries (a) and (b) respectively, implying that this ratio is the same whether calcula= ted using the data for neutrons originating from the same fragment or from opposite fragments in the same fission. However, there is a marked difference between the distribution of real and random ratios observed in each geometry, that is between distributions of R_1 and R_1' and between those of R_2 and R_2'.

These comparisons show evidence of a correlation between the energies of neutrons originating from the same fission. The effect could be partially or predominantly due to the contribution of fragment motion to the neutron energies in the laboratory frame. To investigate this further and to determine whether the results show evidence of neutron energy correlations in the fragment rest frames, the experiments are now being simulated by means of Monte Carlo calculations.

1.   Item 1.1.9, SUNI Annual Research Report (1980)

2.1.5 <u>Spectrum of neutrons from spontaneous fission of ^{252}Cf</u>

        - M S Allie, F D Brooks, W A Cilliers, J V Pilcher

A time-of-flight measurement is being made of the spectrum of neutrons from ^{252}Cf spontaneous fission. The aim is to determine the neutron spectrum in the rest frame of the parent fragment, therefore the experimental method incorporates a measurement of the velocity of the associated fission fragment in coincidende with each neutron detected. The fission source is a thin electrodeposited layer of ^{252}Cf from which normally emitted fragments can escape with negligible energy loss. The fragments are detected by means of a thin film plastic scintillation detector (TFSD) prepared according to the method described by Ajitanand and Yenger[1]. Fission neutrons are detected in an NE321 boron-loaded liquid scintillator, equipped with pulse shape discrimination[2]. The boron-loaded detector is sensitive to a wide range of neutron energies since it detects via proton recoil at high energies ($\geq$ 300 keV) and via the ^{10}B(n,α)^{7}Li reaction at lower energies. The low energy sensitivity is of particular interest in the present experiment since it is at low energies that the largest discrepancies occur between the observed and predicted neutron spectra from ^{252}Cf fission.

The experiment is in its preliminary stages and only limited data have been gathered as yet. It has been reported[3] that the response of TFS detectors is velocity-dependent. We therefore plan to use the TFSD pulse height information to derive the fragment velocity in this experiment. This pulse height, the neutron time-of-flight and some other parameters are recorded on an event (buffer) tape during data acquisition. In the off-line analysis carried out subsequently, each neutron must be attributed either to the fragment actually detected or to the associated undetected fragment, in order to transform the measured neutron energy to the appropriate fragment rest frame. A reliable method for selecting the appropriate fragment has yet to be devised and Monte Carlo simulations of the experiment are planned in which this problem will be

investigated.

1.   N N Ajitanand and C N Yengar, Nucl. Instr. and Meth., 133 (1976) 71

2.   F D Smit et al (item 1.1.2), this report

3.   M L Muga, Nucl. Instr. and Meth. 95 (1971) 349

2.1.6 Neutron spectrometer based on deuterated anthracene

- F D Brooks, D T L Jones*, B R S Simpson, W R McMurray, I J van Heerden**

A neutron spectrometer consisting of a deuterated anthracene scintillation crystal (volume 1.7 cm³) has been described in earlier reports[1]. Recoil deuterons produced by a beam of neutrons passing through the crystal are detected internally and the intensities (pulse heights) and pulse shapes of the result= ing scintillations are analysed to determine the neutron energy spectrum. The spectrometer has unique advantages which arise from the enhanced forward recoil peak in the angular distribution for D(n,n) elastic scattering and from the spatial anisotropy of scintillation properties of the crystal[2]. The former leads to a characteristic peak in the recoil deuteron spectrum for each energy in the incident neutron spectrum. The anisotropic scintillation properties of the crystal are used to select, and therefore to further enhance, this peak.

The current version of the spectrometer incorporates an RCA C31024 photomulti= plier which enhances the energy resolution with a light collection system designed to obtain efficient and uniform illumination of the photocathode from the crystal. The performance of the spectrometer was studied by measuring test spectra from selected (x,n) nuclear reactions. A pulsed beam was used so that the same spectra were also measured, simultaneously, by means of an independent pulsed beam time-of-flight spectrometer, in which the detector was an NE213 liquid scintillator (5 cm diam x 5 cm length) and the flight path length normally was 3.26 m and the system t.o.f. time resolution 2 ns (FWHM).

A comparison of spectra from the $^{11}B(d,n)^{12}C$ reaction indicated that the energy resolution of the deuterated crystal spectrometer was superior to that of the time-of-flight system (0.6 ns m^{-1}) for neutron energies above about 10 MeV. The characteristics of the spectrometer were investigated at incident neutron energies ranging from 1 to 22 MeV. The energy resolution of the spectrometer, in contrast to that of time-of-flight systems, decreases with decreasing neutron energy.

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The crystal is also being used to study spectra from thick target neutron sources, which may be of interest for future radiotherapy facilities[3].

1.   Item 1.1.12, SUNI Annual Research Report (1980)

2.   F D Brooks, Nucl. Instr. and Meth. 162 (1979) 477

3.   D T L Jones and F D Brooks, Paper presented at the Fourth Symposium on Neutron Dosimetry, Munich, West Germany, June 1981

2.1.7 Cross sections for the excitation of the T = 6 analogue-dipole states in the Zr(n,p)Y reaction

- W R McMurray, K Bharuth-Ram*, C M Bartle**, S M Perez

We have previously reported[1] the observation of analogue-dipole states in the reaction $^{90}Zr(n,p)^{90}Y$. The results showed the presence of analogue structure in rough agreement with calculated T = 6 structure for the giant dipole[2]. The smallness of the sample (enriched ^{90}Zr foil) used were responsible for poor statistics and a large background ratio.

More precise cross section data for the Zr(n,p)Y reaction have now been achieved by using larger and thicker samples of natural zirconium. Another objective of the present study was to obtain differential cross sections at more back= ward angles. In the work now reported, differential cross sections have been measured from 0°(± 10°) to 90°(± 10°). As before, the same measurements have been made with similar samples of natural Fe in order to observe proton spectra from a sample which cannot show analogue dipole effects in the proton energy range relevant to the Zr(n,p)Fe reaction, viz. 10-20 MeV.

Smoothed Zr and Fe spectra (summed over 3 angles, 0°, 20°, 50°) were compared. It showed that while for Fe the variation with energy was featureless, there was strong structure at smaller angles, fading at larger angles for zirconium.

It was assumed that the underlying background for zirconium has a shape and angular variation similar to the cross sections observed for iron. Comparison of the measured cross sections with calculations based on the work of Clements and Perez[3] provides strong confirmation for the reaction process postulated by Clements and Perez[4].

1.   Item 1.1.12, SUNI Annual Research Report (1980)

2.   T A Hughes and S Fallieros, Nuclear Isospin, eds., J D Anderson et al

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*   Physics Dept, University of Durban, Westville

** Institute of Nuclear Sciences, Lower Hutt, New Zealand

(Academic Press, N Y, 1969, p. 109)

3.   S M Perez, private communication

4.   C F Clement and S M Perez, Nucl. Phys. A165 (1971) 569

2.2   Charged particle reaction studies

2.2.1   Electromagnetic properties and spins of states in ^{37}Cl

- J J Lawrie, W J Naudé, J W Koen, N J A Rust

Preliminary results on the energies and decay properties of levels in this nucleus together with studies of lifetimes using the DSAM and spin values using Hauser-Feshbach theory, have been reported previously[1]. These investigations have now been completed and the results have been reported[2] together with the results of mixing ratios from angular correlation measurements using Litherland-Ferguson Method II and the ^{34}S$(\alpha,p\gamma)^{37}$Cl reaction.   The results are summarised elsewhere[3].

1.   Item 1.2.1, SUNI Annual Research Report (1980)

2.   J J Lawrie, Ph.D. Thesis, University of Stellenbosch

3.   Item 1.2.1, SUNI Annual Research Report (1981)

2.2.2   Shell model calculations of ^{37}Cl

- J J Lawrie, W J Naudé

Experimental values of level energies, nuclear moments and electromagnetic transition probabilities (see section 1.2.1) were compared[1] with predictions of the many particle shell model using an effective surface delta interaction.

A model of a ^{28}Si-core with 9 extra-core nucleons distributed over active $1s_{\frac{1}{2}}$ and $0d_{\frac{3}{2}}$ subshells with the inclusion of one-particle excitation to either the $0f_{\frac{7}{2}}$ or the $1p_{\frac{3}{2}}$ subshells, was adopted. An additional calculation with active $0d_{\frac{3}{2}}$ and $0f_{\frac{7}{2}}$ subshells and a maximum of three particles in the f-shell, was performed. Although both calculations describe the experimental level scheme satisfactorily, only the larger model space gave an acceptable explanation for the observed electromagnetic transition strengths.

1.   J J Lawrie, Ph.D. Thesis, University of Stellenbosch

2.2.3   The reactions ^{40,48}Ca$(\alpha,p)^{43,51}$Sc

- S Froneman, W J Naudé, N J A Rust, J W Koen

The ^{40,48}Ca$(\alpha,p)^{43,51}$Sc reactions were studied at an incident energy of 12 MeV

with emphasis on the determination of spins in the nuclei ^{43,51}Sc with Hauser-Feshbach theory. The ^{48}Ca(α,p)^{51}Sc reaction proved to be unsatisfactory for this study due to the low yield of the reaction and contamination of the target.

Cross sections for the ^{40}Ca(α,p)^{43}Sc reactions were measured over the incident energy range from 12.022 MeV to 12.082 MeV at laboratory angles of 90°, 120° and 138°. The range of excitation extended to the 24th excited state at 2459 keV in ^{43}Sc.

Fluctuations in the cross sections were analysed with correlation functions. From the auto-correlation functions and observation of the number of peaks in the excitation cross sections, a coherence width of 4.0 ± 1.6 keV was determined for the compound nucleus ^{44}Ti at 16.083 MeV excitation.

Spins of excited states in ^{43}Sc were determined by comparing experimental cross sections with Hauser-Feshbach predictions. The magnitude of transition strengths for gamma-decay in ^{43}Sc as calculated from literature, was also considered. The most probable spin assignments are listed in table 2-1.

TABLE 2-1. SPIN VALUES OF LEVELS IN ^{43}Sc

Level energies in ^{43}Sc (keV)	J^{π} (This work - Item 2.2.3)	J^{π} (Previous assignments)[1]
1830	$\frac{11}{2}^{-}$	$\frac{7}{2}^{-}$; $\frac{11}{2}^{-}$
1884	$\frac{9}{2}^{-}$	$\frac{9}{2}^{-}$; $\frac{5}{2}^{-}$
2106	$\frac{3}{2}$; $\frac{5}{2}$; $\frac{7}{2}^{+}$	$\frac{1}{2}^{+}$; $\frac{3}{2}$; $\frac{5}{2}$; $\frac{7}{2}^{+}$
2114	$\frac{1}{2}$; $\frac{3}{2}$; $\frac{5}{2}$; $\frac{7}{2}^{+}$; $(\frac{7}{2}^{-})$	—
2142	$\frac{3}{2}^{-}$; $\frac{5}{2}^{+}$ *	$\frac{3}{2}$; $\frac{5}{2}^{+}$
2244	$\frac{5}{2}^{-}$; $\frac{7}{2}^{-}$	$(\frac{3}{2} - \frac{7}{2})^{-}$
2360	$\frac{5}{2}^{-}$	$\frac{5}{2}^{-}$; $\frac{9}{2}^{-}$
2459	$\frac{9}{2}^{-}$	$\frac{5}{2}^{-}$; $\frac{9}{2}^{-}$

*$J^{\pi} = \frac{3}{2}^{+}$ eliminated due to an unacceptable large M2-strength if a weak branch to the ground state is accepted[2].

1. P M Endt, C van der Leun, Nucl. Phys. A130 (1978) 646
2. G C Ball, J S Forster, F Ingebretsen, Nucl. Phys. A180 (1972) 517

2.2.4 The reaction $^{40}Ar(\alpha,p\gamma)^{43}K$

- L D Olivier, J W Koen, W J Naudé

Studies of this reaction have been reported previously[1]. Analyses of the experimental results obtained are being continued.

1. Item 1.2.2, SUNI Annual Research Report (1980)