INDC(ITY)-011/G

NUCLEAR DATA ACTIVITIES IN ITALY

SUMMARY PROGRESS REPORT TO THE 15TH INDC MEETING

BY

E. MENAPACE

I n d i c e

E N E A - DIPARTIMENTO TECNOLOGIE INTERSETTORIALI DI BASE
CRE "E. Clementel" - Via Mazzini 2 - BOLOGNA (Italy)

1. Experimental activities

Laboratorio Interazioni Neutroniche - Divisione Fisica e Calcolo Scientifico.

i) Resonance photo-neutron measurements

C. Coceva, A. Mauri, M. Magnani, P. Bartolomei

Time-of-flight measurements have been performed of (γ, n) reaction on ^{25}Mg, using a 30 g enriched sample at the CNR electron linear accelerator in Medicina.
Burst width of the bremsstrahlung gamma rays impinging on the sample was 4 ns, the length of the flight paths being 10.5 m.
The angular distribution of the emitted neutrons was determined by performing the measurement simultaneously on seven different flight-paths, at angles from 55° to 140° with respect to the gamma-ray direction.
Two types of detectors have been used to cover the neutron energy range from 40 keV to 1.6 MeV:
a) ^{6}Li-loaded, Ce-activated scintillating glasses
b) Proton recoil plastic scintillators.

Neutron resonances have been observed, both corresponding to neutron decays to the ground state and to the first 2^+ excited state of ^{24}Mg.

Several resonances have been observed, due to M1 and E2 excitation of ^{25}Mg, and to d-wave emission of neutrons.
Some new resonances are observed, which could not be detected in experiments on neutron induced reactions on ^{24}Mg.
Preliminary results of this work were presented at the Santa Fe Conference, 1985.

Reference: "A Facility for Resonance Photo-Neutron Measurements" C. Coceva, A. Mauri, M. Magnani, P. Bartolomei, Rad. Eff., vol. 96, p. 65.

ii) Review on neutron energy standards for white neutron sources

C. Coceva

Some new experimental results and calculations bearing on standard energies used as calibration points for neutron spectrometers, and their influence on values and errors of the 1982 INDC/NEANDC Standard List were examined and

and presented to '86 IAEA AGM on "Neutron Source Properties" in Leningrad.
On this basis,a revised list has been presented, to be considered as a draft proposed for the next updated issue of the INDC/NEANDC nuclear standards file.
Critical aspects of the absolute determination of resonance energies by neutron time-of-flight have been examined and some recommendations given for the correct use of the data and for future work in this field.

2. Theoretical activities

Laboratorio Dati Nucleari e Codici - Divisione Fisica e Calcolo Scientifico.

i) Nuclear structure and level density microscopic calculations

G. Reffo, M. Herman(*), F. Fabbri

Particle-hole state densities have been investigated by use of combinatorial calculations in the frame of BCS theory and shell model spherical and deformed nuclei have been considered.
Williams formula proved to fit our results provided the average single particle state density g and the energy shift S (to determine an effective excitation energy inclusive of shell shift and pairing interaction) are taken as fit parameters in the calculations.
These results indicated that use of Williams formula is neither trivial nor straight forward and in many cases ambiguous,even if parametrized by a fit procedure.

Work to be published

(*) Guest researcher

G. Maino, M. Vaccari, A. Ventura(**)

The PHINTL code for nuclear structure calculations (low-lying collective states and related electromagnetic transitions of even-even nuclei) has been adapted and implemented on the ENEA IBM 370/168 computer. This code has been originally written by P. Van Isacker (University of Gent) for a VAX computer. PHINTL is based on the interacting boson model, allowing for inclusion of one g-boson excitation, in addition to the usual s and d-boson configurations. Calculations of low-lying collective states have been made for medium and heavy-mass nuclei, for even-even Cr and Os isotopes.

G. Maino, E. Menapace

The parity distribution of nuclear excited states has been investigated in the framework of a statistical microscopic Nilsson-BCS formalism. Calculations performed for medium-mass nuclei (50 A 66) have shown that the parity equiprobability holds at excitation energies greater than 15 MeV. A simple phenomenological expression for nuclear level densities has been proposed, in order to reproduce the theoretical NBCS calculations and to be used in nuclear reaction computing codes.

Reference:

1. G. Maino, E. Menapace, in Proceed. of Int. Conf. on Nuclear Data for Basic and Applied Science, Santa Fe, NM, May 13-17, 1985; and Radiation Effects (in press).

G. Maino, A. Ventura(**)

In the frame of the interacting boson model, describing simultaneously low-lying and high-lying collective states, calculations of elastic and inelastic scattering and absorption of photons at energies around the giant dipole

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(**) Laboratorio Interazioni Neutroniche

resonance (10 to 20 MeV) have been performed for Nd, Sm and Os isotopes.

References:

- Photon Scattering in the Interacting Boson Model,
  G. Maino, A. Ventura, L. Zuffi, F. Iachello - Phys. Lett. 152(1985)17 by -soft Nuclei"
- Photon Scattering,
  G. Maino, A. Ventura, P. Van Isacker, L. Zuffi - Phys. Rev. C, 33(1986)1089.

ii) Neutron reaction data and methods

G. Reffo, F. Fabbri

Neutron capture process has been treated in the frame of the exciton model. This puts in evidence a fairly good agreement between n=1 and n=3 preequilibrium component and direct-semidirect contributions to neutron capture.

Reference:

G. Reffo, F. Fabbri, "Neutron Capture in the frame of the unified exciton model", Proceedings of the 4th Int. Conf. on Nuclear Reaction Mechanisms, Varenna (Italy), June 10-15, 1985, pag. 61. Edited by E. Gadioli.

G. Reffo, F. Fabbri

Neutron capture cross sections of Kr isotopes were calculated in the KeV region in terms of optical model and statistical model of compound nucleus reaction mechanism. The work performed in the frame of a cooperation with the Van de Graaff group in KFK Karlsruhe provides measured capture cross section of stable isotopes using a C D - detector system in conjunction with time-of- flight technique.
Neutron capture of Krypton isotopes are needed among others because mixture of these isotopes are used to tag fuel assemblies.

References:

G. Walter, B. Lengers, F. Kaeppeler, Z. Y. Bao , G. Reffo, F. Fabbri: to appear in NSE June-July 1986.

G. Reffo, C. Costa(°), F. Fabbri

Preequilibrium model

The effects have been investigated of nucleon reflection and refraction at the nuclear surface, as well as of the bound nucleon-nucleon scattering in the unified model for equilibrium and preequilibrium emissions with angular momentum conservation.
The theoretical approach to nuclear data estimates, in particular to the particle-hole state density and to pre-equilibrium reaction mechanism and their parametrization, have been brought-up also in the frame of reciprocal working visits and stages between Laboratorio Dati Nucleari, ENEA, Bologna and US Laboratories at LLL, LANL and BNL.
The nuclear model code system IDA was extensively tested and improved including more accurate calculations of emitted particle and gamma-ray spectra and angular distributions.

Reference:

"Effect of refraction and bound nucleon-nucleon scattering in preequilibrium angular distribution of (n,n') reactions", Proceed. Europhysics Study Conf. on Nuclear Reactions" Creete, Greece (1985).

3. Nuclear data evaluation

i) Nuclear data for fusion

V.Benzi, F.Fabbri, E.Menapace,G.C.Panini,G.Reffo, M.Rosetti

In the frame of the European project for the evaluated data library for fusion applications EFF, a revised evaluation for natural Al and Si was performed in ENDF/B-V format with special care to neutron inelastic scattering, (n,2n) and absorption (n,p; nα ; n,γ ; n,t; n,d) cross sections. Main differencies were found with respect to ENDF/B-V for Al-27(n,p) , of importance for different applications (dosimetry, activativation) too.

ii) Gamma production data

F. Fabbri, G. Maino, A. Mengoni

Photon production cross sections and spectra following neutron-induced reactions on Cr^{50} ,Cr^{52} ,Cr^{53} ,Cr^{54} and

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(°) Guest researcher

^{nat}Cr, have been calculated in the energy range from 1 KeV to 8 MeV. In this energy interval, the main sources of emitted gamma-rays are neutron radiative capture and inelastic scattering processes. The latter is predominant in the MeV region, just above the threshold energy.
Gamma-ray cascades originating from (n, γ) and (n,n'γ) reactions have been described in the framework of the statistical model. Starting from the calculated neutron cross sections and photon spectra, an evaluated data file in ENDF/B format has been obtained both for stable Cr isotopes and natural element.

Reference:

A. Mengoni, F. Fabbri, G. Maino, ENEA report RT/TIB/85/38.

iii) Fission product data

E. Menapace, M. Vaccari and H. Gruppelaar(°°)

In the frame of the European cooperation on Fission Product Data, a revised evaluation of Pd-105, of highest priority for fast reactor long term reactivity, has been completed taking into account both microscopic and integral experiment indications.

G. Reffo, F. Fabbri

Neutron capture cross sections have been estimated for the following targets: Se-76,-78,-79,-80; Br-79,-81; Kr-78, -79,-80,-81,-82,-83 and -84 (1 KeV En 1 MeV); Sm-148,-149, -150 (1 KeV En 100 KeV); Os-187 (1 KeV En 70 KeV); Ir-191, -193 (300 KeV En 1.3 MeV).

Reference:

M. Herman, A. Marcinkowski, G. Reffo, "Fast neutron capture on Ir Isotopes" Acta Phys. Polonica, vol. B16, N.1.

iv) Actinide data

V. Benzi

(alfa,n) reactions in fuel oxides have been theoretically

(°°) Cooperation with ECN-Petten

investigated and succesfully compared with the recently available experimental data.

Reference:

"The (alfa,n) neutron yield and energy spectrum in oxide nuclear fuels" Proc. 3rd IAEA AGM on Transactinium Isotope Nuclear Data.

4. Nuclear Data Management and Processing

i) Nuclear Data Archive

G.C. Panini, M. Cuccoli

The following sets of Evaluated Nuclear Data have been received and have been put into the standard management and verification procedures:

- JEF-1, the reference European-Japanese Nuclear Data File for fission reactor applications including 300 materials. Several consistency and physical checks have been performed on it for internal purposes;
- EFF-1, the European Fusion File, (33 materials) concerning data of interest for fusion applications. The whole library has been extensively and deeply tested and processed (see below);
- INDL/V, the International Nuclear Data Library in ENDF/B-V format including various evaluations of different origin.

In the framework of the international cooperation for ENDF/B-VI format, a participation to the May '85 CSEWG Meeting in Brookhaven took place as observer on behalf of the NEANDC.

Reference:

G.C. Panini, "Highlights of the ENDF-6 Format", RT/TIB/85/32.

ii) Nuclear Data Processing

G.C. Panini, M. Pescarini

The following codes or chains of codes have been put on operation in the ENEA Computer Network:

- GROUPXS-3, the ECN-Petten code for processing Energy-Angle correlated data from ENDF/B-V and -IV formatted data;
- THEMIS, the French version of NJOY code with improvements in the unresolved resonance processing and in the input/output capabilities;

- TRANSX, the ancillary code of NJOY for the producing problem oriented group libraries;
- the family of codes for the management of ENDF/B data ('85 version);
- the Cullen family of codes for the nuclear data display and processing ('86 version).

Particular efforts have been spent in producing the following group libraries:

GEFF-1, a group library from EFF-1, in cooperation with other European laboratories (ECN-Petten, CEA-Saclay, KFK-Karlsruhe, NEA-DB) and an activation library in a 25 group structure for the national fast reactor project;

SAND-II scheme library for the most important materials upon request of the National Electric Power Agency (ENEL);

ANISN format problem dependent library originated from VITAMIN-C for shielding computations in discrete ordinate and Montecarlo codes, upon request of national nuclear industry.

Reference:

M.G. Borgia, G.C. Panini, M. Pescarini, "Messa a punto di una catena di processamento dati su un calcolo di schermaggio per un BWR utilizzando il sistema AMPX-II e le librerie VITAMIN-C ed EURLIB-4 a confronto". Report RT-TIB(86)12.

iii) Data Validation

G.C. Panini, M. Pescarini

A comparison brtween ENDF/B-IV originated multigroup libraries (VITAMIN-C and EURLIB-4) has carried out. The AMPX-II system of codes and ANISN have been used for this purpose. The results show the relevance of the self-shielding effects in the Bondarenko approximation for shielding calculations.

Reference:

M.G. Borgia, G.C. Panini, M. Pescarini, "Comparison between EURLIB-4 and VITAMIN-C Libraries with respect to a Shielding Reference Problem". Report RT-TIB(86)4 presented at KTG/ENS Int. Sem. on "Nuclear Data, Cross Section Libraries and their Application in Nuclear Technology" Bonn, Oct. 1-2,1985.

ENEA - DIPARTIMENTO REATTORI VELOCI
Divisione Metodi di Progettazione - CRE, Casaccia, Roma

Nuclear Data Testing by Integral Experimental Analysis

A. De Carli, M. Guma

Group libraries for shielding calculations, obtained from the main basic data files, among which VITAMIN-C and EURLIB from ENDF/B-IV and VITAMIN-J from JEF-1, have been tested against integral experiments presented to the NEACRP shielding benchmark exercise (ref. NEACRP-L-263). In particular for Na and Mn materials calculated values from VITAMIN-J fitted reasonably well experimental results. The validation of JEF derived library with respect to ASPIS Fe experiment is planned.

CESNEF - POLITECNICO DI MILANO - 20133 Milano, Italy

A. Cesana, V. Sangiust, M. Terrani, R. Dierckx(*)

i) An irradiation was executed in a spallation neutron spectrum at the beam stop of LAMPF, Los Alamos.
This neutron spectrum is much harder than a fission spectrum, about 5-10% of the neutrons lie above 10 MeV and have energies up to some hundreds of MeV.
The irradiation has taken place from October 1982 through February 1983, and reached a fluence of 2.10^{19} n/cm^2.
Temperature during irradiation was 120°C.
The neutron spectrum is monitored by seven sets of monitor foils. From the foil activities the spectrum was deduced by unfolding codes.
On one set of foils total He production measurements and solid transmutation production by chemical analysis method were executed. The measured quantities of He and solid transmutation products were compared with theoretical predictions.

ii) In the frame of the European cooperation(**) in the field of high energy neutron dosimetry and its applications in fusion devides and spallation sources three topics were covered:

1. Development of neutron dosimetry in eventual spallation sources for radiation damage experiments in fusion simulated radiation environments by measurements of neutron spectra and fluences in spallation neutron spectra at the TRIUMF facility;

2. Neutron techniques applied for diagnostics in experimental tokamak devices, with particular attention to measurements at JET-Culham;

3. Cross section libraries up to some hundreds of MeV, based on calculations with the ALICE code (up to 200 MeV) and on model calculations at the University of Vienna.

(*) JRC Ispra, I 21020 Ispra (Varese), Italy

(**) Collaborators are: O.N. Jarvis, B. Syme, B. D'Hont, F. Hegedus, W. Matthes, W.G. Alberts.

UNIVERSITA' DI ANCONA - Dipartimento di Scienze dei Materiali e Istituto di Fisica Medica

Neutron Interferometric Determination of the Coherent Scattering Length of ^{232}Th, Natural Uranium and ^{238}U.

R. Caciuffo and F. Rustichelli (*)

Very accurate determination of the neutron coherent scattering length b of natural uranium, of ^{238}U and of ^{232}Th has been performed with the neutron interferometer installed at the High Flux Reactor of the Institute Lane - Langevin, Grenoble. The following values have been obtained for neutrons of wavelength

$\lambda = 1.8389\ (6)\ \mathring{A}$:

$b\ (^{232}Th) = 10.52 \pm 0.03$ fm |1|

$b\ (^{nat}U) = 8.417 \pm 0.005$ fm |2|

$b\ (^{238}U)\quad 8.407 \pm 0.007$ fm |2|

Taking into account the contribution to the scattering length due to the interaction of the neutron with the electrostatic potential of a bound electronic charge and to the neutron-electron interaction, the nuclear force scattering length of natural uranium was then obtained |2| :

$b_{NF}\ (^{nat}U) = 8.409 \pm 0.0062$ fm

References:

|1| A. Boef, U. Bonse, R. Caciuffo, J.M. Fournier, L. Manes, U. Kischko, F. Rustichelli, T. Wroblzwskj, Acta Crystallographica, B41, 81-83 (1985).

|2| A. Boeuf, R. Caciuffo, R. Rebonato, F. Rustichelli, J.M. Fournier, U. Kischko, L. Manes, Phys. Rev. Lett. 49, 1986-89, 1982.

(*) Cooperation with: A. Boeuf, CEC, JRC, Ispra, Italy
U. Bonse, Universitat Dortmund, FRG
J.M. Fournier, CEN, Grenoble, France
L. Manes, CEC, JRC, Karlsruhe, FRG
J. Kischko and T. Wroblewski, Universitat of Dortmund, FRG.

Dipartimento di Fisica - Università di Milano - Sezione INFN - Milano, Italy

E. Gadioli, E. Gadioli Erba, P. Guazzoni, L. Zetta(*)

1. Elastic Scattering of α-particles on ^{140}Ce and ^{141}Pr

The elastically scattered α-particles from ^{140}Ce and ^{141}Pr targets were measured at incident energies of 19, 23, 97, 32, 37.7 MeV at the XTU-Tandem, from lab = 5° up to 165°.
This experiment was performed to obtain the optical model potentials for the α-channel to be used in the DWBA analysis of (n,α) and (p,α) reactions.
The experimental set-up consisted of the scattering chamber at +20°, two SSD detectors (5° apart) with standard electronics and the SADAT data acquisition system.
The α-particle angular distributions for the ^{140}Ce(α,α) reaction are presented as contribution to Legnaro NL Annual Report 1985.

(*) Cooperation with: M. Jaskoda, Institute for Nuclear Studies, Warsaw, Poland.

2. Neutron Spectrum Measurements at a 40 MeV Proton Cyclotron

C. Birattari, A. Salomone

The activation technique was applied to get information on energy and angular distribution of neutrons produced by 40 MeV protons striking accelerator structures, beam pipes, beam stoppers, etc. The aim of the work was devoted to find a minimum set of targets to be employed in neutron spectra evaluation so to obtain information, although of low angular and energy resolution, accurate enough for radiation protection purposes.
A set of seven reactions, involving only three materials (Al, Co, Au) was identified and tested.
A comparison of unfolding complete codes (Lyra and Sand) was also carried out.
In tab. 1 are reported the seven reactions, threshold energy and gamma emission employed in evaluating the neutron activation induced.
In tab. 2 the neutron yield, per μC and mster of 40 MeV protons bombarding Al, Fe, Cu, Ta and stainless steel structures, integrated upon the full energy range at 0°, 45° and 90°.

Reference:

Health Physics 49, n. 5, pp 919-936 (1985).

Table 1 Reactions chosen for use in the final set of measurements

REACTION	THRES. (MeV)	$t_{1/2}$	MAIN γ EMISSION Energy (MeV) and Probability (Le/d)
$^{27}Al\ (n,\alpha)\ ^{24}Na$	5.	15.03 h	1.368(1.000) , 2.754(0.999)
$^{59}Co\ (n,p)\ ^{59}Fe$	0.8	44.6 d	1.099(0.565) , 1.291(0.435)
$^{59}Co\ (n,2n)\ ^{58}Co$	10.5	71.3 d	0.8107(0.994)
$^{59}Co\ (n,3n)\ ^{57}Co$	20.	270. d	0.122(0.856) , 0.136(0.111)
$^{197}Au(n\gamma)\ ^{198}Au$	--	2.69 d	0.4118(0.947) , 0.676(0.0106)
$^{197}Au(n,2n)\ ^{196}Au$	8.	6.18 d	0.333(0.238) , 0.355(0.876)
$^{197}Au(n,4n)\ ^{194}Au$	24.	39.5 h	0.293(0.108) , 0.328(0.616)

Table 2 Neutron yields, per μC of 40-MeV protons, per msr, integrated over the full energy range at 0°, 45° and 90°

	0°	45°	90°
Al	$1.32\ 10^{7}$	$1.17\ 10^{7}$	$1.01\ 10^{7}$
Fe	$2.53\ 10^{7}$	$2.38\ 10^{7}$	$2.30\ 10^{7}$
Cu	$3.11\ 10^{7}$	$2.85\ 10^{7}$	$2.70\ 10^{7}$
Ta	$4.82\ 10^{7}$	$4.65\ 10^{7}$	$4.55\ 10^{7}$
S.S.	$2.31\ 10^{7}$	$2.12\ 10^{7}$	$2.07\ 10^{7}$

3. Milan Superconducting Cyclotron Project

E. Acerbi, F. Aghion, F. Alessandria, G. Baccaglioni, G. Bellomo, C. Birattari, C. De Martinis, F. Fabrizi, A. Ferrari, D. Giove, P. Michelato, C. Pagani, L. Rossi, L. Serafini, G. Variaco

A three sector superconductivity cyclotron with a k=800 and a k_{foc} =200 is under construction since 1981 at the Milan University.
The cyclotron has been designed as a booster for a 15 MeV Tandem with maximum energies of 100 MeV/nucl. for fully stripped light ions down to 20 MeV/nucl. for uranium ions.
The machine will also be equipped with axial injection from an external E.C.R. ion source.
The pole radius is 90 cm and average magnetic field will span between 22 and 48 kgauss, with a corresponding R.F. frequency range between 15 and 48 MHz.
Peak dee voltage is 100 kV with harmonic operation mode $h \approx 2$.
A schematic vertical cross section of the cyclotron is presented in fig. 1.
Tests of the single components, magnet, coils, cavity resonator, power supplies, cryostat, vacuum system, computer control have been competed.
Assembling is in process. Magnetic measurements are planned in the next autumn. First accelerated beams are expected at the end of the next year.

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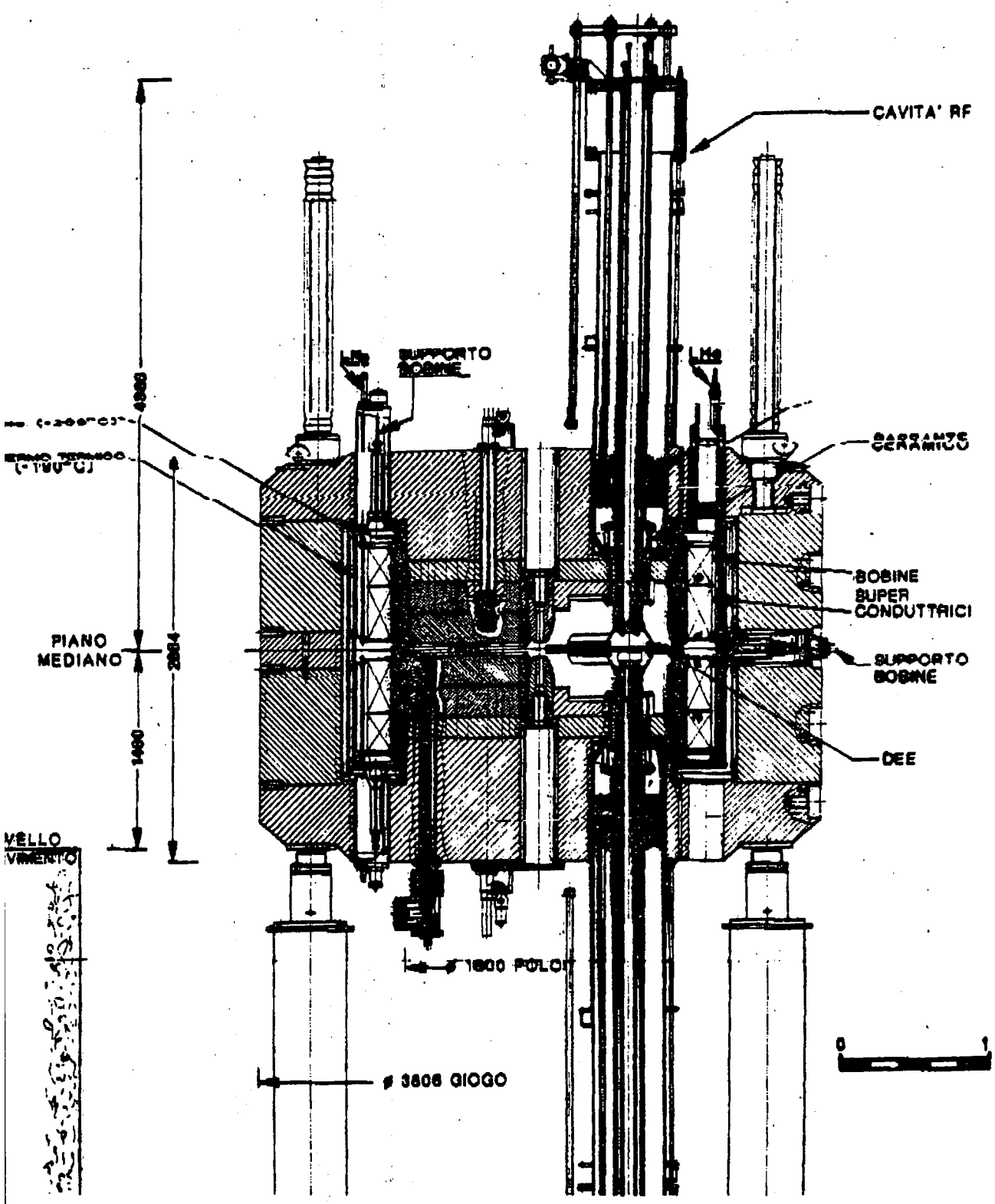
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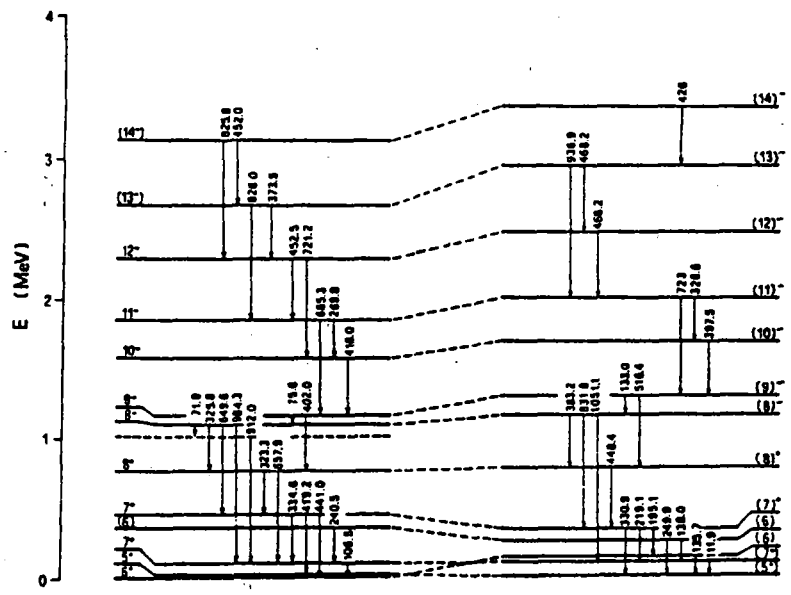
DIPARTIMENTO DI FISICA DELL'UNIVERSITA' DI FIRENZE - INFN - Sezione di Firenze

A.M. Bizzeti Sona, P. Blasi, A.A. Stefanini and G. Galeazzi(*)

1. Conversion Electron Measurements in ^{98}Tc and ^{100}Rh

In a previous note [1] is reported the high spin level scheme of ^{98}Tc, determined with the ^{94}Zr(^{7}Li,3n)^{98}Tc reaction.
Some checks on the parity of ^{98}Tc levels, by means of conversion electron measurements have been undertaken.
The experiment has been performed at the Tandem XTU with the ^{94}Zr(^{7}Li,3n)^{98}Tc reaction, using a ^{7}Li beam of 26.5 MeV.
As an example for the results obtained, small parts of the electron spectra of ^{98}Tc and ^{100}Rh indicate that Tc transitions of 416 and 441 keV are consistent with any mixture of M1 and E2 and the 419 keV one with the expected E2 multipolarity, while the 402 keV transition is only consistent with the expected E2 multipolarity, while the 402 keV transition is only consistent with the E1 attribution.
From a similar analysis of the other lines, it is possible to assign the level parities shown in the figure for high-spin level schemes of ^{98}Tc and ^{100}Rh.



Partial level scheme of ^{98}Tc (from ref.2) and ^{100}Rh with the parity attributions obtained in the present work.

(*) Laboratori Nazionali di Legnaro

References:

1) A.M. Bizzeti-Sona, P. Blasi, A.A. Stefanini, Annual Report 1984, Laboratori Nazionali di Legnaro, p. 10.

2) A.M. Bizzeti-Sona, P. Blasi, A.A. Stefanini, Proc. Second Int. Conf. on Nucleus-Nucleus Collisions, (Visby, 1985) Vol. I, p. 110.

2. Electric Monopole Transition in ^{76}Se

A. Giannatiempo, A. Nannini, A. Passeri, A. Perego and P. Sona

Electric monopole transitions between the 0^+_2 , 0^+_1 and 2^+_2 , 2^+_1 levels in ^{76}Se, populated in the decay of ^{76}Br, were investigated. It was possible to extract the strength $\rho(E0^2)$ of the $0^+_2 \longrightarrow 0^+_1$ transition

$$|\rho(E0;\ 0^+_2 \longrightarrow 0^+_1)| = 0.17\pm0.08.$$

Concerning the $2^+_2 \longrightarrow 2^+_1$, 657 keV transition, the value of q^2 (defined as the ratio of the E0 to E2 strengths in the same transition) was derived

$$q^2(2^+_2 \longrightarrow 2^+_1) = -0.056\pm0.057$$

which rules out any significant E0 component in the $2^+_2 \longrightarrow 2^+_1$ transition.

3. Electric Monopole Transitions in ^{106}Ru

A. Giannatiempo, A. Passeri, A. Perego and P. Sona

The decay of ^{102}Rh ($T_{1/2}$ = 207^d) has been investigated with the aim of studying the electric monopole transition (E0) between $0^+_2 \rightarrow 0^+_1$, $0^+_3 \rightarrow 0^+_1$ and $2^+_2 \rightarrow 2^+_1$ levels in ^{102}Ru[1]. The ^{102}Rh source was obtained by bombarding a 700 ug/cm^2 ^{102}Ru target (98.7% enriched) with a 2μA proton beam of the CN Van de Graaff accelerator. The bombardment was performed at 6 MeV proton energy and lasted 72 hours.

Spectra of internal conversion electron were recorded by means of the magnetic transport electron spectrometer[2] operating at the Physics Department in Florence. The spectrometer was used in conjunction with a Si(Li) detector 500 mm^2 x 3 mm. Gamma rays were simultaneously recorded via a multiplexed acquisition system by a 10 cm^2 HP germanium detector.

The intensity ratio q^2 of the K-internal conversion electron for the $0^+_2 \rightarrow 0^+_1$, 944 keV transition to the $0^+_2 \rightarrow 2^+_1$, 468 keV transition was determined to be:

$$q^2 = I_K(944;\ 0^+_2 \rightarrow 0^+_1)/I_K(468;\ 0^+_2 \rightarrow 2^+_1) = 0.18 \pm 0.02$$

For the corresponding ratio concerning the decay of the 0^+_3 level we found the upper limit:

$$q^2 = I_K(1837;\ 0^+_3 \rightarrow 0^+_1)/I_K(1362;\ 0^+_3 \rightarrow 2^+_1) \lesssim 3.7 \times 10^{-2}$$

The E0 component in the $2^+_2 \rightarrow 2^+_1$, 628 keV transition was obtained from the measurement of the K-internal conversion coefficient α_K through the relation:

$$\alpha_K = \frac{\alpha_K(M1) + \delta^2 \alpha_K(E2)}{1 + \delta^2}$$

where q^2 is the ratio of E0 to E2 transition strenght for the k-conversion and δ is the gamma mixing ratio E2/M1.

From the experimental value $\alpha_K = (2.28 \pm 0.24) \times 10^{-3}$ and the known δ^2 the upper limit $q^2 \lesssim 0.029$ was derived.

The strenght ρ^2(E0) for the $0^+_2 \rightarrow 0^+_1$ and $2^+_2 \rightarrow 2^+_1$ transition was obtained, according to the standard expression[4], from the q^2 values and from known lifetimes of the 0^+_2 and 2^+_2 levels:

$$|\rho(E0;\ 0^+_2 \rightarrow 0^+_1)| = 0.12 \pm 0.01 \text{ and } |\rho(E0;\ 2^+_2 \rightarrow 2^+_1)| \lesssim 0.17.$$

Since the lifetime of the 0^+_3 level is unknown it was only possible to derive for the $0^+_3 \rightarrow 0^+_1$ transition an upper limit 0.019 for the ratio B(E0)/B(E2) of the E0 to E2 reduced transition probabilities. The experimental results were discussed in the frame of a schematic IBA-1 model following the study by Stachel et al.[5]. The analysis seems to confirm that the 0^+_2 level is to be considered an intruder one, as suggested in ref.(4), and lends further support to the hypothesis that the 0^+_3 state is to be identified as the first excited 0^+ state predicted by the IBA model.

(1) A. Giannatiempo, A. Passeri, A. Perego, P. Sona: Phys.Rev. C33, 1024 (1986).
(2) T. Fazzini, A. Giannatiempo, A. Perego: Nucl.Instr. Methods 211, 125 (1983).
(3) B. Singh and H.V. Taylor: Nucl.Phys. A115, 70 (1970).
(4) G. Winter, H. Sodan: Nucl.Phys. A114, 629 (1968).
(5) J. Stachel, P. Van Isacker and K. Heyde: Phys.Rev. C25, 650 (1982).

DIPARTIMENTO DI FISICA UNIVERSITA' DI TRIESTE - INFN, Sezione di Trieste

1. A Study of the $^{139}La(n,n'\gamma)^{139}La$ Reaction

U. Abbondanno, A. Boiti and F. Demanins

As a part of a research programme devoted to the spectroscopy of some medium and heavy nuclei by means of the study of the γ-rays following the inelastic scattering of neutrons (1) the $^{139}La(n,n'\gamma)^{139}La$ reaction has been studied for incident neutron energies ranging from 1.3 MeV to 2.7 MeV. The measurements presented in this note were performed at the 7 MV Van de Graaff accelerator of the Laboratori Nazionali di Legnaro (LNL, Padua). A proton current of about 1.5 μA, with a pulse width of 3ns, impinged on a titanium absorbed tritium target (0.84 Ci/cm^3), producing neutrons by means of the $^3H(p,n)^3He$ reaction. A cylindrical sample of chemically (99,91%) pure ^{139}La(201 g), contained in a thin aluminum box, 4.5 cm in diameter and 5.0 cm in height, was placed at a distance of 10 cm from the tritium target, at an angle of 0° relative to the direction of the incident proton beam. The emitted γ-rays were recorded by means of a 42 cm^3 true-coaxial Ge(Li) detector (efficiency 10% energy resolution $\sim$3 keV at E=1.33 MeV, time resolution $\sim$ 4 ns). In order to discriminate between the background due to neutrons scattered in the detector and surrounding materials and the γ-rays following the de-excitation of ^{139}La, the pulsed-beam time-of-flight technique was used, with a flight path of 60 cm. The results of the measurements were the γ-ray spectra for the $^{139}La(n,n'\gamma)^{139}La$ reaction at incident neutron energies from 1.3 MeV to 2.7 MeV, in energy steps of 0.1 MeV, recorded at an angle θ = 90° with respect to the incident proton beam.

The results of these measurements are the decay scheme of the ^{139}La nucleus and a complete discussion on the spin values of their levels, performed by comparing the measured excitation functions for the de-excitation γ-rays with the previsions of the statistical theory of the compound nucleus. In this way, we propose, and compare to the previous results, the spins of the levels at Ex = 1208 keV, Ex = 1218 keV, Ex = 1381 keV, Ex = 1256 keV, Ex = 1421 keV, Ex = 1476 keV, Ex = 1536 keV, Ex = 1558 keV, Ex = 1578 keV, Ex = 1682 keV, Ex = 1715 keV, Ex = 1766 keV, Ex = 1854 keV, Ex = 1919 keV, Ex = 1939 keV, Ex = 1961 keV.

(1) See for example:

U. Abbondanno, A. Boiti and F. Demanins
In proceedings of the International Symposium on in-beam nuclear Spectroscopy
Debrecen, Hungary, May 14-18, 1984
Edited by ZS. Dombradi and T. Fenyes, pg. 105.

2. A Neutron Time-of-Flight Facility for the LNL Tandem Laboratory

U. Abbondanno, A. Boiti, F. Demanins

The aim of the present work is to study the neutron spectra emitted in a known (^{3}He,n) reaction, by employing an array of neutron detectors as time-of-flight (TOF) spectrometer, in order to determine the working possibilities in this research field at the LNL Tandem Laboratory.

Because of the relatively large distance needed to obtain a good TOF separation at the Tandem energies, large detecting volumes are required to obtain an adequate solid angle and detecting efficiency. Therefore we have constructed an array of eight scintillation spectrometers. This device employs scintillator cells of cilindrical shape made of aluminum, 1 mm thick, 12.5 cm in diameter and 5 cm long. The inside surface of the cells is coated with NE 561 reflecting paint prepared from a polyuretane resin. Each cell is filled with NE 213 liquid scintillator and is wiewed by its own XP 2040 photomultiplier, which is mounted on the axis of the scintillating cell and immersed in the liquid. Calibrated light sources, coupled with each photocatode, are employed to check the spectrometer gain during long time measurements. Fast signals are taken from the dynode 12, while the anode provides the signal for a fast pulse shape discrimination (40 ns of dead time). The pulse-shape-discrimination unit analyzes the shape of the pulses from gamma-rays or scattered protons and from light control sources. A microprocessor system inspects ciclically and stabilizes the gain of the eight detector elements acting on the high voltage power supplies. The time resolution of the array, with the electronic and the control system in operation, is 720 ps, 70 ps more than that of a single channel.

The array was tested at LNL Tandem laboratory during a run in october 1985.

To illustrate the performances of the instrument, the TOF spectrum of neutrons emitted at 20° from the reaction $^{12}C(^3He,n)^{14}O$ at $E_{^3He}$= 21 MeV, with a 200 $\mu g/cm^2$ target of carbon, is shown in Fig. 1. These data were taken with an integrated target current of 0.14 nC at the 20° channel (first measuring point) in the east experimental room of the Tandem laboratory. The flight path was 10 m and the detectors were placed near the existing experimental facilities (large scattering chamber, gamma chamber et al.) without any kind of shields or collimators. The background has not been subtracted. The beam pulses, with 800-900 ps FWHM, had a repetition rate of 2.5 MHz.

The Fig. 1 shows the expected positions for the groups (NX) of neutrons corresponding to the ^{14}O level excitation energies (E_x). Moreover the same parameters, the neutron energies (E_n), the total time of flight (t) for the

10 m flight path and the differential reaction cross section (σ (20°)) (1) are reported in the following table.

NX	E_x (MeV)	E_n (MeV)	t (ns)	(20°) (mbarn/sr)
0	0	18.61	167.5	.08
1	5.17	13.09	199.8	1.0
2	5.91	12.29	206.2	
3	6.29	11.87	209.7	15.0
4	6.59	11.54	212.7	
5	7.78	10.24	225.9	
6	9.74	8.04	254.8	
7	9.94	7.82	258.5	

A successive measurement on ^{30}S, produced in the $^{28}Si(^{3}He,n)$ ^{30}S reaction with a target of 100 $\mu g/cm^2$, was suspended owing to the exaustion of the He gas at the Tandem source. Even though the number of pulses accumulated in this spectrum for each neutron group is low, we refind in Fig. 2 all the expected peaks between E_x=0 and E_x=7.57 MeV. Moreover, the peaks corresponding to higher excitation energies show the existence in the ^{30}S of levels at E_x= = 7.88-8.64-9.97-10.34-11.21 MeV.

Considering these results, the overall performance of the spectrometric system (pulsed LNL Tandem accelerator and TOF spectrometer) is regarded as atisfactory in wiew of the neutron spectrometry work.

(1) D.H. Feng, K.N. Geller and N. Klein, Phys. Rev. C 18(1978) 33.

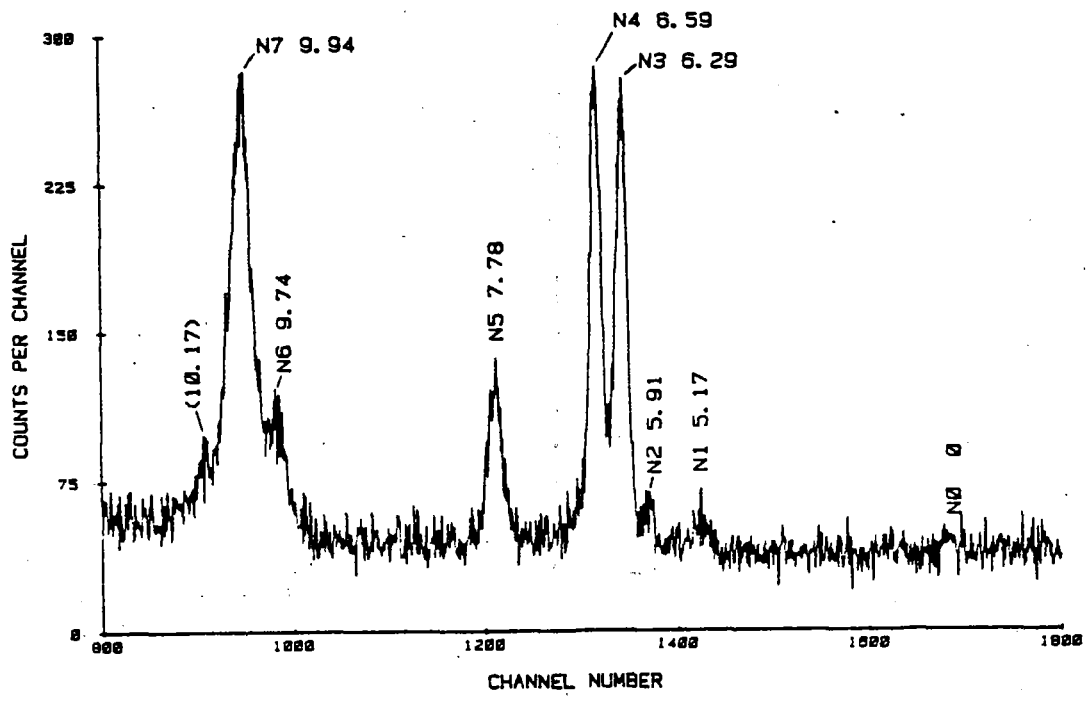


Fig. 1 - The neutron TOF spectrum of ^{14}O from the reaction $^{12}C(^{3}He,n)^{14}O$ at $E_{^{3}He}$=21 MeV and Θ =20°, expected positions for the neutron groups NX and level excitation energies (Ex, MeV).

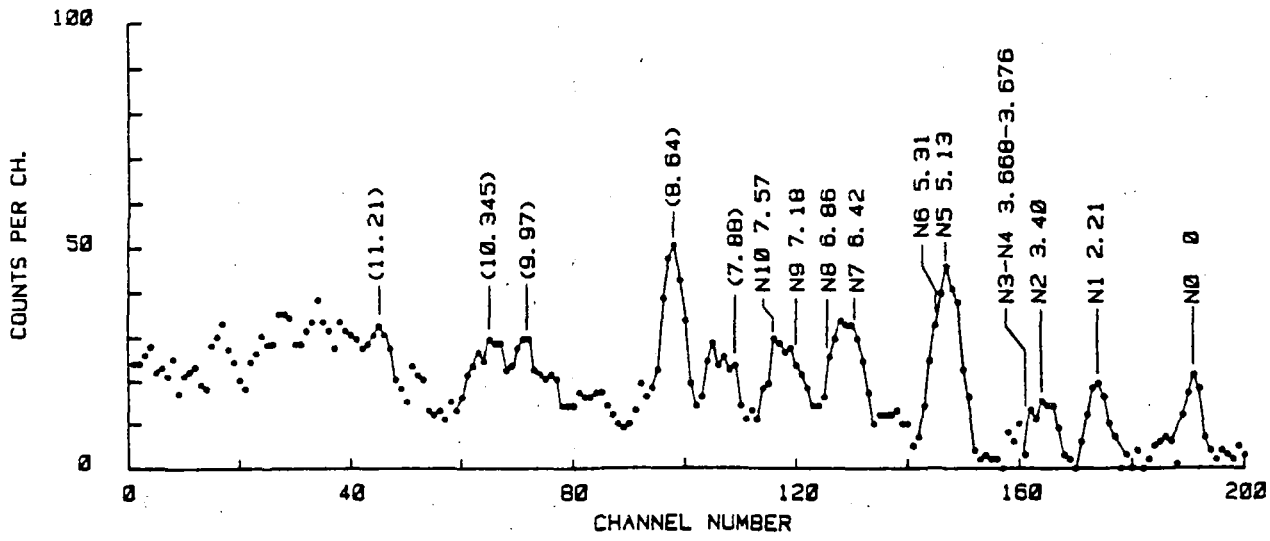


Fig. 2 - The neutron TOF spectrum of ^{30}S from the rection $^{28}Si(^{3}He,n)^{30}S$ at $E_{^{3}He}$=21 MeV and Θ =20°, expected positions for the neutron groups NX and level excitation energies (Ex, MeV).

3. A Neutron-Gamma Coincidence Facility for Studying the (He,n-γ) and (He,x-n-γ) Reactions

U. Abbondanno, A. Boiti, F. Demanins

The (^{3}He,n) two proton transfer reaction on light and medium nuclei has been often used during the last years as source of spectroscopic information about the residual proton rich nuclei and about the reaction mechanism itself. A striking feature of this reaction is the selective population of states with proton pairing and the strong excitation in L=0 transfers. It is then possible to study proton pairing states even in the presence of transitions with L$\geq$2. In spite of this, the use of this reaction is limited by the problems connected with the requirement of an adequate resolution in the neutron spectrometry. However, when the analysis is extended to the γ-de-excitation radiation in coincidence with neutrons, the lack of resolution in the neutron spectrometry may be offset by the high energy resolution of the Ge(Li) γ-ray detectors. Then, in order to determine the level scheme and to construct the γ-decay scheme of the residual nucleus, these coincidence data are complementary to the neutron time-of-flight experiments.

The experimental equipment used for carrying out the measurements described in this report consists of a NE 213 (5 l) liquid scintillator, associated with eight XP 2040 photomultipliers, for neutron detection. This detector is coupled to a fast neutron-gamma discriminating electronic system which also control the gain of the photomultipliers. The γ-rays are detected in a true coaxial Ge(Li) detector with a mean energy resolution of 3 keV, a time resolution of 5 ns, and an efficiency of 30%.

The performance of this experimental device was tested at the CN Van de Graff accelerator laboratory in november 1985.

Targets of 120 $\mu g/cm^2$ natural Mg (with abundances of 78.99% ^{24}Mg, 10% ^{25}Mg and 11.01% ^{26}Mg) and of 100 $\mu g/cm^2$ natural Si (92.23% ^{28}Si, 4.67% ^{29}Si and 3.1% ^{30}Si) on Ta backings, were bombarded with ^{3}He particles at energy of 12.6 MeV. The excited states studied in ^{26}Si and ^{25,26,27}Al, were populated by the ^{24}Mg(^{3}He,n) and ^{24,25,26}Mg(^{3}He,p-n) reactions, respectively. The excited states in ^{30}S and ^{29,31}P were populated by the ^{28}Si(^{3}He,n) and ^{28,30}Si(^{3}He,p-n) reactions, respectively. The neutron gamma coincidence spectra taken with the neutron detector at 0° and the Ge(Li) spectrometer at 90° are shown in Fig. 1 and Fig. 2. The former spectrum was obtained bombarding the Mg target, the latter by bombarding the Si target.

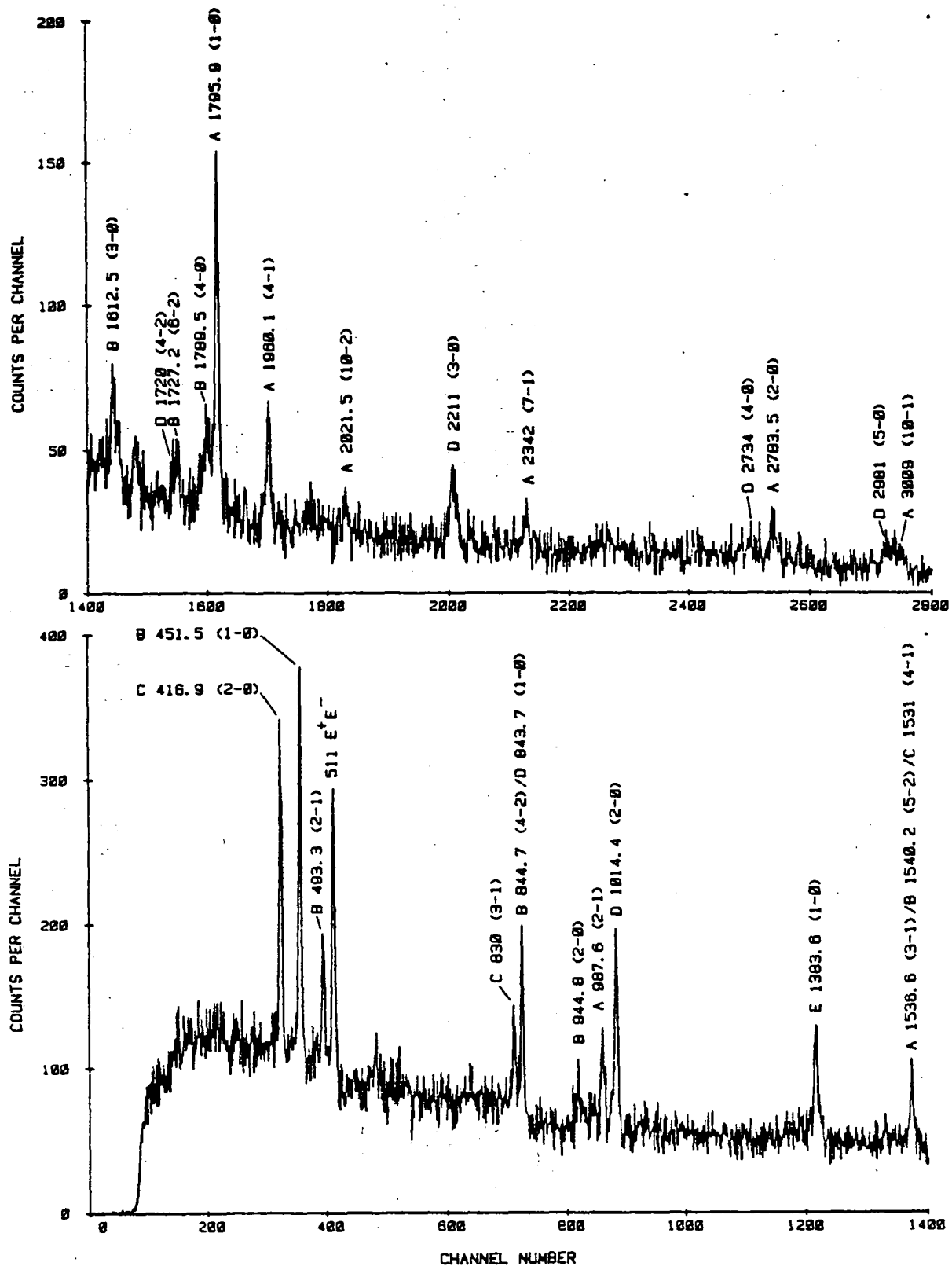


Fig. 1 - Neutron-coincident gamma-ray spectrum from the reactions - A: $^{24}Mg(^{3}He,n\text{-}\gamma)^{26}Si$, B: $^{24}Mg(^{3}He,p\text{-}n\text{-}\gamma)^{25}Al$, C: $^{25}Mg(^{3}He,p\text{-}n\text{-}\gamma)^{26}Al$, D: $^{26}Mg(^{3}He,p\text{-}n\text{-}\gamma)^{27}Al$, E: $^{28}Si(^{3}He,p\text{-}n\text{-}\gamma)^{29}P$. The gamma rays are labelled by their energy (keV) and transition between the levels of the residual nucleus.

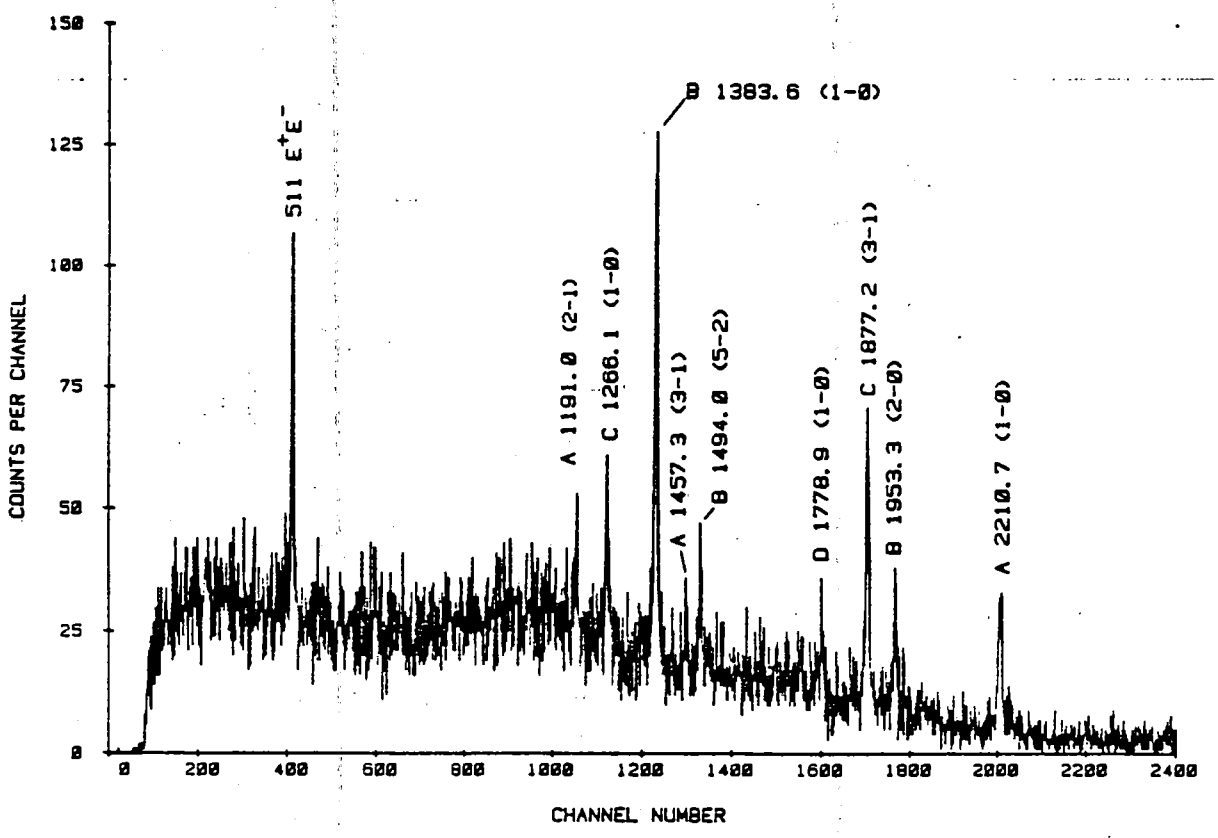


Fig. 2 - Neutron-coincident gamma-ray spectrum from the reactions - A: $^{28}Si(^{3}He,n-\gamma)^{30}S$, B: $^{28}Si(^{3}He,p-n-\gamma)^{29}P$, C: $^{30}Si(^{3}He,p-n-\gamma)^{31}P$, D: $^{30}Si(^{3}He,\alpha-n-\gamma)^{28}Si$. The gamma-rays are labelled by their energy (keV) and transition between the levels of the residual nucleus.

DIPARTIMENTO DI FISICA DELL'UNIVERSITA' and INFN - Sezione di Bologna - Via Irnerio, 46 - 40126 Bologna, Italy

1. Production of High-Energy Photons in Fast Neutron Radiative Capture (°)

G. Longo (*)

The differential cross section for the production of high-energy γ-rays (10-50 MeV) due to radiative capture of fast neutrons by ^{48}Ti and Ni, are calculated by means of the direct-semidirect (DSD) model.
From the spectra of emitted γ-rays calculated for E_n =5-50 MeV with ΔE_n=0.2 MeV and for θ_γ =0°-180° with $\Delta\theta_\gamma$ = 10°, the angular- and energy-dependent photoproduction cross sections are obtained as average values for photons produced in one-MeV energy intervals. The hard γ-rays considered, though constituting only a small fraction of the photon spectra from neutron-induced reactions, could be of interest for shielding purposes connected with fusion reactors and fast neutron facilities.
The present results together with those for neutron radiative capture by Ca and Sn /1/ and preliminary calculations for Cr and Fe, show that the strength and position of giant multipole resonances highly influence the angular distributions of high-energy γ-rays emitted by the constituents of the structural materials. It follows that DSD calculations could allow useful predictions on the relative yield of high-energy γ-rays emitted in different directions with respect to incident neutrons.

Reference:

/1/ G. Longo, F. Fabbri and C. Mazzotti, Proc. 6th Kiev Conf. on Neutron Physics, Oct. 2-6, 1983, vol. 1, pp. 277-283, Moscow (1984).

(°) G. Longo, F. Fabbri: Contribution to the International Conference on Nuclear Data for Basic and Applied Science, May 13-17, 1985, Santa Fe, USA (to be published in "Radiation Effects", 1986).

(*) Cooperation with F. Fabbri, ENEA, Dipartimento TIB.

2. Energy Dependence of the j-Effect in Radiative Capture of Polarized Nucleons

G. Longo

The direct-semidirect model is used to investigate the sensitivity of polarized neutron capture to the final-state j value ($j = \ell+\frac{1}{2}$) for a given ℓ. It is shown that predictions of the model together with data from polarization measurements can be useful as a tool both in assigning j-values to final states and in obtaining information about giant multipole resonances.

Reference:

G. Longo, Proc. Sixth Symp. Polar. Phenom. in Nucl. Phys., Osaka, 1985, J. Phys. Soc. Jpn. 55 (1986) Suppl. p. 1022.

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1. Backward Angle Resonances in the Yield of (α,α') Reactions for ^{19}Fe, ^{31}P and ^{35}Cl.

D. Bazzacco, F. Brandolini, K. Loewenich, P. Pavan and C. Rossi Alvarez

In 1984 we started an experimental program devoted to the systematic search of backward angle resonances in (α, α') reactions on light nuclei. Nuclear states excited in this way can be used as convenient probes for g-factors or transient field measurements.
Yields for ^{20}Ne, ^{24}Mg, ^{28}Si and ^{32}S have been previously reported /1/. More recently some odd A nuclei have been considered and the yields to the first $3/2^+$ and $5/2^+$ in ^{31}P, to the first $9/2^+$ and $13/2^+$ levels in ^{19}F and to the first $5/2^+$ and $7/2^-$ levels in ^{35}Cl have been measured. For several of the strongest resonances the angular distribution or the logarithmic derivative of the deexciting γ-rays have also been measured.
The yields were measured in the energy range 8-14 MeV in steps of 30 keV.

Reference:

/1/ D. Bazzacco, F. Brandolini, F. Pavan, C. Rossi Alvarez, R. Zannoni, M. De Poli, LNL Annual Report 1984.

2. Direct and Compound Gamma Decay of the Giant Quadrupole Resonance of ^{208}Pb

P.F. Bortignon

The gamma decay of the isoscalar giant quadrupole resonance (GQR) in ^{208}Pb is estimated /1/ to have comparable probability through the compound nucleus as by direct decay. Therefore, the compound decay can even mask the direct decay, depending on the specific system studied.
The quantity measured is the gamma branching ratio P, which we may express as a sum of a direct component and a compound component. The experimental ratio P can be safely used to measure giant-resonance strength in situations where the compound decay background is negligible. This is the case, e.g., of the nucleus ^{90}Zr, because the p-wave strength function is very large, or for ^{209}Bi, where the density of transition channels from the compound is very large.

Reference:

/1/ J.R. Beene, G.F. Bertsch, P.F. Bortignon and R.A. Broglia, Phys. Lett 164B (1985) 19.

3. Neutron Microdosimetry of High Energy Neutron Beams

P. Colautti, M. Cutaia, G. Talpo, G. Tornielli

In order to study the quality of the neutron beams which can be produced at the Tandem accelerator, the Li(p,n) reaction was used with a proton beam of 28 MeV of energy. The 1 mm thick natural lithium target was supported with an infinite pure graphite backing.
Because of the high negative Q-values of the $^{12}C(p,n)$ reaction (Q=-18.4 MeV) the neutrons produced in the backing are expected to have an average energy well lower than that of the neutron peak and then a quite different quality.
The microdosimetric spectrum of the neutrons produced in the lithium plus graphite backing was compared with that of the neutrons produced in the backing only. For the comparison the two spectra have been normalized to their maxima. The high energy neutrons produce a low quality proton peak, but a big yield of α-particles and heavier ions of higher y.

4. A New Facility for Radiobiological Studies at CN Accelerator

M. Belli*, S. Mazzuccato, M. Morando, G. Moschini, O. Sapora*, M.A. Tabocchini*

Particle beams are widely used in the medical fields for therapeutic purposes.
A low energy accelerator like CN accelerator is of particular interest when the radiobiological efficiency of proton and alpha particle beams near the Bragg peak is the main goal of the research.
For this purpose, a new dedicated beam line has been setted up, making possible air irradiation of living cells with uniform proton and alpha beam.

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5. High-Energy Mass Spectrometry with the XTU Tandem Accelerator

R. Bonetti [*], C. Cernigoi [+], E. Fioretto [*], G.F. Herzog [°], T.H. Kruse [°], G.M. Marcazzan [*], R.K. Moniot [°°], G. Moschini, G. Pauli [+], R.A. Ricci, R. Rui [+], P. Spolaore, B.M. Stievano and C. Tuniz [+].

The analytical properties intrinsic in a Tandem accelerator and its beam transport system permit the detection of rare atoms with original abundancies 10^{-16} of the matrix.
An accelerator mass spectrometry (AMS) system based on 16 MV Tandem of the Laboratori Nazionali di Legnaro has been developed to detect a wide variety of rare nuclides for applications to geology, cosmochronology, archaelogy, hydrology and fundamental nuclear physics.
The following studies have been planned:

i) Measurements of cosmogenic isotopes.
ii) Measurement of ^{36}Cl and ^{129}I in ground waters to obtain chronological and hydrodinamic information. The main interest in such dating relates to the underground storage of radioactive material from nuclear reactors.
iii) Measurement of the Double Beta Decay (DBD) with the geochemical method in geologically dated minerals.

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