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PROGRESS REPORT ON NUCLEAR DATA ACTIVITIES IN INDIA FOR THE PERIOD FROM JANUARY 1986 TO JUNE 1987

Compiled by

R. P. Anand

Nuclear Physics Division

1987

B.A.R.C. - 1377

GOVERNMENT OF INDIA
ATOMIC ENERGY COMMISSION

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Descriptors

NEUTRON REACTIONS

CAPTURE

CROSS SECTIONS

MULTIGROUP THEORY

FISSION YIELD

FISSION

EXPERIMENTAL DATA

COMPUTER CALCULATIONS

DECAY

RESEARCH PROGRAMS

INDIA

PREFACE

The present progress report on Nuclear Data Activities in India is the fifth in the current new series of progress reports, the first of which was brought out in the year 1981. This report covers the period from January, 86 to June, 87. It contains information about measurements, evaluations, compilations and processing of nuclear data and other related works being carried out mainly at B.A.R.C., Bombay and I.G.C.A.R., Kalpakkam, the two nuclear and reactor research centres in this country.

It may be worth mentioning here that an IAEA interregional training course on "Processing of Nuclear Data for Use in Reactor Applications" was held at Bhabha Atomic Research Centre, Bombay during 31 March - 25 April, 1986. This course was designed to provide participants with a working knowledge of the methods currently used to process nuclear data for use in reactor applications. It comprised of lectures as well as computer exercises. The scope of the course included an introduction to currently available nuclear data libraries and their applications in specific reactor applications, processing of resonance parameters, Doppler broadening, the multigroup method and self-shielding. It also included the lectures on the accuracy of the results obtained and on the sensitivity analysis, which can be used to determine the sensitivity of the integral reactor parameters to nuclear data uncertainties.

Most of the write-ups in this report describe work in progress and these are not to be regarded as publications or quoted without permission from the authors.

(S.S. Kapoor)
Member, International Nuclear Data Committee.

CONTENTS

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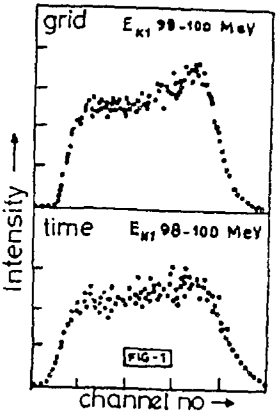
FISSION FRAGMENT MASS ENERGY AND ANGLE MEASUREMENTS IN $U^{235}(n_{th},f)$ USING BACK-TO-BACK GRIDDED IONISATION CHAMBER

M.N. Rao[+], Aruna Nijasure and R.K. Choudhury
Nuclear Physics Division, BARC, Bombay 400 085, India.

Detailed measurements on the correlations between mass and energies of fission fragments have yielded significant information on the mechanism of the fission process. In many studies one also requires a knowledge of fission fragment angle with respect to a given direction. It has been reported in the past[1)] that by using a parallel plate back-to-back gridded ionisation chamber, one can simultaneously measure mass, energy of the fragments and also the angle of emission of fragments with respect to the electric field direction. It has been shown that from a simultaneous measurement of the grid and collector pulse heights, it is possible to measure angles with a resolution of 6^0 to 10^0. The information on the fission fragment angle can also be obtained from the time difference between the grid and collector pulses and this method has not been explored in the past. The aim of the present investigations is two-fold: i) to explore the possibility of improving the angular resolution by simultaneous recording of pulse heights as well as the timing signals of the grids and collectors in a back-to-back gridded ionisation chamber, and ii) to study properties of cold fission fragments.

The set up consists of a parallel plate ionisation chamber as described in ref.1. The grid-cathode and grid-collector distances are 2.1 and 0.7 cm respectively. A ^{235}U source (20 $\mu g/cm^2$) prepared on thin VYNS backing is mounted in the cathode plane and the chamber is filled with a Ar(90%)+CH_4(10%) mixture at a pressure of 1.5 atm. Voltages on the cathode and grids were optimised to give maximum peak to valley ratio in the collector pulse height spectra on both the sides. The pulse heights of grids, collectors and signals corresponding to the time difference between the grid and collector pulses were recorded for off line analysis.

The collector pulse heights were calibrated assuming the energies of heavy and light fragment peaks to be 70.5 and 101.5 meV respectively[2)]. The fragment masses were obtained by mass momentum conservation relations. The distributions in grid pulse height and the time difference between the grid and collector pulses corresponding to a given fragment energy bin are shown in fig.1. The analysis for obtaining the angle from these distributions is still in progress. In the following we present certain results on the mass-energy correlations with the aim of understanding the behaviour of large kinetic energy events. Fig.2 shows the variation of $\overline{M}_H$ and σM_H with the total fragment kinetic energy. It is seen that for very large total kinetic energies, the average heavy fragment mass approaches 132 amu. This results has been seen in some earlier studies and attributed to the doubly closed shell configuration of the heavy fragment at this mass number. The width in the mass distribution decreases continuously with increasing total energy. In fig.3, the mass distributions of the light fragments are shown for very large single fragment kinetic energy windows. By selecting large kinetic energy of one of the fragments, one is preferentially studying events where the fragments are comparatively cold. It is seen that fine structures due to odd-even Z effects are present. These results will be further examined after electronically collimating the events to forward angles and there by improving the resolution of the data.



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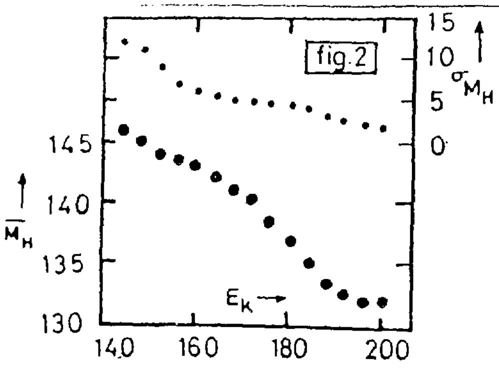

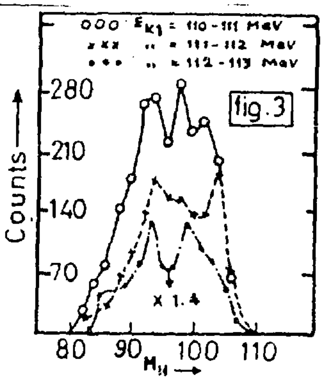

COMPUTED NEUTRON CROSS-SECTIONS AT 14 MeV FOR SOME TRACE ELEMENTS

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R.K. Mohindra, Physics Department, Kurukshetra University, Kurukshetra 132119, Haryana.

Abstract: Cross-sections of twelve important trace-elements ^{24}Mg, ^{28}Si, ^{48}Ti, ^{51}V, ^{52}Cr, ^{55}Mn, ^{59}Co, ^{63}Cu, ^{64}Zn, ^{80}Se, ^{88}Sr and ^{127}I have been computed for reactions like (n,p); (n,n'); (n,α); (n,n'p); (n,2n); (n,n'α); (n,αn'), (n,αp); (n,2α); (n,pn'), (n,pα) and (n,2p) at 14 MeV, using a diffused edge optical model potential. The computed cross-sections are quite suitable for calculating induced activities of the above trace-elements for 14 MeV Neutron Activation Analyis. Level densities used for these computations are those of Lang & Le-Couteur. The agreement between computed and experimental values is reasonable in general with few large deviations. Out of the large number of cross-sections computed here, only a few are amenable to experimental measurements and therefore therefore these theoretical estimates can be quite useful in many nuclear design applications.

CALCULATIONS AND RESULTS: The detailed outlines and various theoretical formulae used have been described earlier by Wadhwa and Mohindra (1), for both primary and secondary reactions. The compound nucleus model using the optical potential parameters given by Mani et al (2) for proton and neutron penetrabilities, has been used. The inverse reaction cross-sections for alpha particles have been taken from the tabulations of Huizenga and Igo (3). The level density formula of Lang and Le-Couteur as discussed (1) has been used in the present computations. The secondary reaction cross-sections formulae based on the evaporation theory have been reported earlier (1). The gamma ray emission has been ignored in computations. The computed cross sections will be compared with the available experimental cross-sections. The agreement between available experimental and our computed cross-sections is reasonable in general, but in some reactions, the deviations seem to be large. This brings us to an important conclusion that the present theory for primary and secondary cross-sections needs great refinments to predict all primary and secondary cross-sections with reasonable accuracy (4,5). This theory fails even to predict all primary cross-sections listed herewith to a fair degree of accuracy. The calculated cross-sections can be profitably used for evaluating induced activities and radiation doses to man via these trace-isotopes. Recently it has been reported by Khanchi and Mohindra (4) that the estimates of induced activities of $^{75}Ge^{*}$ from ^{75}As $(n,p)^{75}Ge^{*}$ reaction at 14.0 MeV can be used for the trace elemental analysis of ^{75}As in samples of hair, nail and liver. Khanchi et al (5) recently reported such investigations in detail for nine medium mass trace elements.

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USE OF NUCLEAR MODELS IN THE COMPUTATION OF NEUTRON INDUCED REACTION CROSS-SECTIONS OF STRUCTURAL ELEMENTS

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International Atomic Energy Agency has sponsored a co-ordinated Research Programme on 'Methods For The Calculation Of Fast Neutron Nuclear Data For Structural Materials'. The objective of this programme is to assess the reliability of calculational models and recommend them for the computation of neutron induced reaction cross-sections for structural materials which find a frequent usage in fission and fusion reactors.

Under this project spherical optical model, multistep Hauser-Feshbach statistical theory, precompound exciton model of Kalbach, BrinkAxel model of radiative capture, Distorted Wave Born Approximation based direct reaction model, geometry dependent hybrid model in combination with Weisskopf's evaporation model and the unified exciton model of pre-equilibrium decay have been utilized to investigate the following binary and tertiary reaction cross-sections of Fe-56 and Nb-93 in the energy range 1 to 26 MeV.

(i) total, reaction, elastic, inelastic and level excitation cross-sections.

(ii) (n,p), (n,pn), (n,np), (n,α), $(n,n\alpha)$, (n,γ), (n,2n) and (n,3n) cross-sections.

(iii) energy spectra and double differential reaction crosssections of the emitted neutron, proton and alpha particles and

(iv) total neutron, hydrogen, helium and gammaray production crosssections.

Some of the results have been reported /1/ at the First CRP Meeting held at Bologna, Italy during October 1986. Crosssections for Cr-52 and Ni-58 are being investigated in order to bring out the relative merits and limitations of the above mentioned nuclear models as calculational tools.

Reference

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MULTIGROUP CROSS-SECTIONS OF Pa-231, Pa-233 AND U-233

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35 group cross-sections with P_3-anisotropic scattering matrices have been generated for Pa-231, Pa-233 and U-233 which belong to the category of thorium fuel cycle elements. Pa231 is the naturally occurring isotopically pure fissionable material and is also present in large quantities in the spent fuels of reactors operated on the Th-U233 cycle. In order to study the criticality aspects of this element from the safety point of view 35 group cross-sections for this actinide have been derived by combining the BARC evaluated data /1/ in the energy range 1 to 20 MeV with the Pa-233 data of JENDL-2 file below 1 MeV.

Basic cross-section data for Pa-233 and U-233 have been taken from JENDL-2 file as the data for these elements listed in ENDF/B-IV library are rather old and especially for U-233 the data are not well represented in the resonance energy range.

eferences

1. Amar Sinha, V.K. Shukla and S.B. Garg, "Evaluation of Neutron Cross-Sections for Pa-231 and Pa-233", Report No. NDE (BARC)-7 (1981)

EVALUATION OF SELF SHIELDED GROUP CROSS-SECTIONS AND COMPUTATION OF DOPPLER COEFFICIENT IN KAMINI REACTOR

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KAMINI is a 30 KW BeO reflected and water moderated neutron source reactor fuelled with U-233-Al alloy and is currently being built at Indira Gandhi Centre for Atomic Research, Kalpakkam. Doppler coefficient of reactivity is one of the vital safety coefficients and in order to estimate it, self-shielded 35 group cross-sections of all the core and reflector elements were determined as a function of temperature and composition using the BARC-35 group cross-section library /1/ and the SPHINX code /2/.

Utilizing the self-shielded group cross-sections neutron multiplication factors were estimated at temperatures of interest and the Doppler coefficient of reactivity was determined and found to be slightly positive.

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INVESTIGATION OF THE LARGE DISCREPANCY IN CAPTURE CROSS SECTION IN 10 TO 25 EV ENERGY RANGE FOR TH-232

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It was pointed out (Ganesan, 1986) that the large discrepancy for the capture cross section in 10 eV - 25 eV energy range for Th-232 needs further investigations. We give below recent results giving a comparison of available values of infinite dilution cross sections:

ENDL-84:	flat weighted (Howerton, 1986)	: 1.32 barns
	IGCAR Kalpakkam; flat weighted	: 1.32 barns
	IGCAR Kalpakkam; E weighted	: 1.735 barns
JENDL-2:	IGCAR Kalpakkam; E weighted	: 0.654 barns
ENDL-78:	E weighted (Paviotti and Chalhoub, 1983)	: 3.25 barns
ENDF/B-IV:	(Paviotti and Chalhoub, 1983) E weighted	: 0.852 barns

The E weighted value is higher than flat weighted value because the group boundaries 10 eV - 21.5 eV covers the lower portion of 21.78 eV resonance. The cross section on the lower side of the peak increases with energy; hence E weighting which gives increased weights to higher values of cross sections in the group gives a higher value of the group cross section. This example also illustrates that in the calculation of weighting function can further unfavourably propagate the basic discrepancies present as a function of energy in cross sections.

It thus appears that ENDL-84 and ENDL-78 have too high capture cross sections for Th-232 in 10 eV to 21.5 eV energy region.

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Howerton R.J. (1986) Private Communication.

Paviotti C.R. and Chalhoub E.S. (1983) "Comparison of Seventeen Nuclides Cross Sections from ENDF/B-IV and ENDL-78", INDC(BZL)-6/GV, IAEA, Vienna.

EXPERIENCES IN THE THEORETICAL PREDICTIONS OF NEUTRON CAPTURE CROSS SECTIONS FOR TH-232 USING ABAREX CODE IN 400 KEV TO 2 MEV ENERGY REGION

S. Ganesan, S. Subbarathnam,* M.M. Ramanadhan and V. Gopalakrishnan
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The optical-statistical model program ABAREX of late Prof. Peter Moldaeur has been successfully commissioned at IGCAR, Kalpakkam and several test runs were performed. The sample case for the calculation of neutron capture cross sections for U-238 given by (Moldaeur, 1983) was successfully reproduced by us.

For Th-232, a spherical optical potential with a derivative Woods-Saxon form factor and Thomas spin-orbit term (in the conventional notation) is followed. The optical parameters used for the present run for Th-232 are:

$$V = 46.4 - 0.3\,E \text{ MeV}; \quad W = 5.8 + 0.4\,E \text{ MeV}$$
$$r = r_o' = 1.26 \text{ fm}; \; a = 0.63 \text{ fm}; \; a' = 0.52 \text{ fm};$$
$$V_{so} = 6.2 \text{ MeV}; \quad (r_o)_{so} = 1.12 \text{ fm}; \quad a_{so} = 0.47 \text{ fm}$$

where E represents the laboratory energy of the neutrons in MeV.

We specified 27 levels, the energy of the last level being at 1182.5 keV. A continuum level density starting at the highest discrete level and derived from a Fermi gas temperature of 0.385 MeV, a shift of -0.25 MeV and a spin cut off of 5.93. The energies, spins and parities of the 27 discrete levels are taken from (Sheldon, 1986) The neutron binding energy for the compound nucleus Th-233 is specified to be 4.7864 MeV.

In our calculations, we found, as expected that the effect of WFCF on calculated capture cross sections decreases with increase in the incident neutron energy. Around 20 keV ignoring the WFCF increases calculated capture cross setion by 30% and at 200 keV by less than 2%. The γ ray strength function was varied from 0.0015 to 0.002 and it was found in the present calculations that the value of 0.002 gives a good visual fit in 400 keV to 2 MeV energy region. For energies less than 200 keV a lower value of 0.0015 was found to be preferable for a good visual fit. The calculated capture cross sections at energies 0.4 to 2 Mev for Th-232 corresponding to one set of parameters input to ABAREX code are shown in Fig.1.

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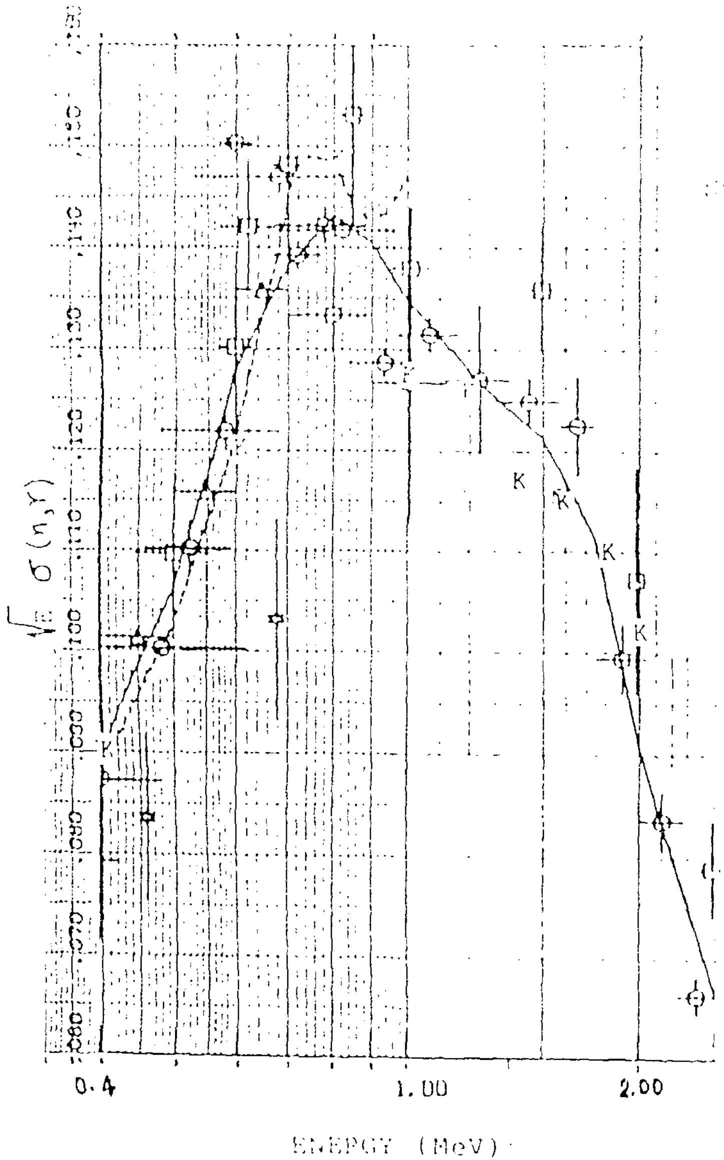
Moldaeur P.A. Report No. ANL-83-4, p.125-132 (1983).

Sheldon E. et al., (1986) J. Phys. G.12, 237-255.

Fig. 1. The Neutron Capture Cross Section of [illegible]



Symbol	Authors	Reference
-----	W.P. Poenitz	79 Knoxv., 363 (1979)
——	J. Meadows et al.	ANL/NDM-35 (1978)
	M. Bhat	BNL-NCS-[illegible]
Θ	M. Lindner et al.	NSE 59, [illegible] (1976)
⊞	W.P. Poenitz et al.	ANL/NDM-42 (1978)
Δ	R.L. Macklin et al.	NSE 64, 849 (1977)
✡	B.M. Jain	78 Harwell (1978)
K	Kalpakkam Calculations	

CROSS SECTION MEASUREMENT WITH JET :RECOIL TRANSPORT

A.Chakraborti, D.P.Choudhury, S.Gangadharan, J.Arunachalam, R.M.Iyer
Chemical Group, B.A.R.C.

The helium jet recoil transport system(1) set up at VECC, Calcutta has been used to measure production cross section for some short lived nuclides.

Compared to the standard foil activation technique, two additional information, the transport erficiency and the range of the recoil, are required for computing cross-sections using the gas jet technique. The transport efficiency for a short-lived product is taken to be equal to that of the longer-lived isotope or isomer of the same element for which the transport efficiency can be measured with a catcher foil; thus for example the transport efficiency for ^{61}Zn and ^{60}Zn is taken as the same as that for ^{62}Zn and ^{63}Zn. The recoil ranges have been determined experimentally using the approach outlined in the literature ; the recoil range of the short-lived product is taken to be equ al to that of its longer lived isomer/isotope. Table gives production cross-section measurement data for ^{60}Cu, ^{61}Zn, ^{159m}Ho (8.3 sec.). For the measurement of the short-lived nuclides ($t_{\frac{1}{2}} \leq 5$ min.), activities were counted on-line using a 10% HPGe detector in close geometry with respect to the collection spot (end of the glass thimble) in the detection chamber. In the case of the 8.3 sec. ^{159m}Ho activity, the activities were collected for 15 secs. allowed to cool for 15 secs. and were then counted for 3 secs. This cycle was repeated (with a gap of 4-5 min.between each cycle) many times for enough statistics. The cross-section value for the relatively longer lived ^{60}Cu, was measured by foil activation as well and is given for ~~comkparsi~~ comparison. The agreement in the values through the two approaches is quite satisfactory, thus validating the methodology of the gas jet system for the measurement of cross-section. The cross-section data for ^{60}Zn, ^{61}Zn and ^{159m}Ho are indicative of the poten tial of this approach, which also enables the determination of isomer ratios, over activation with pneumatic transport (rabbit) technique which is widely used:

- ability to measure (cross-section) even when the target is highly radioactive, as the recoils are separated from the target and then transported to a low background area.
- provides an ideally thin and point source of low activity, thus minimising errors from extended sources, self absorption and counting losses.
- cyclic "activation-measurement" is possible which can improve the counting statistics subject of course to the constancy of experimental condition, in particular the beam current.
- Selective transport is possible through the choice of transport parameters.

The major limitations of the gas jet rtechnique are

- measurements at too low a bombarding energy are not possible due to the low recoil energy; however, in foil activation, the problem is one of 'recoil loss' at high bombarding energy.
- knowledge / measurement of transport efficiency and recoil range and the errors axsi arising herefrom.

(1) HELIUM JET RECOIL TRNSPORT SET UP FOR CHEMISTRY AND NUCLEAR APPLICATIONS AT VECC

A.Chakrabarti, D.P.Chawdhury, S.Gangadharan, J.Arunachalam and R.M.Iyer

Submitted for publication

Production cross section measurements

Target	E_{α} (MeV)	Product nuclide ($t_{\frac{1}{2}}$)	Recoil range (um)	GJRT σ (mb)	Foil Activation σ (mb)
Copper	36	^{60}Cu (23.4 min.)	0.53±0.02	300±15	286±15
	25	^{60}Cu	0.33±0.02	79±2	62±2
	25	^{60}Zn (144 sec)	0.32±0.02	15±2	-
	25	^{61}Zn (86 sec)	0.32±0.02	78±12	-
Terbium	41	159mHo (8.3 secs)	0.07±0.006	47±5	-

STACKED FOIL ACTIVATION YIELD FOR APPLICATION IN WEAR ANALYSIS USING THIN LAYER ACTIVATION

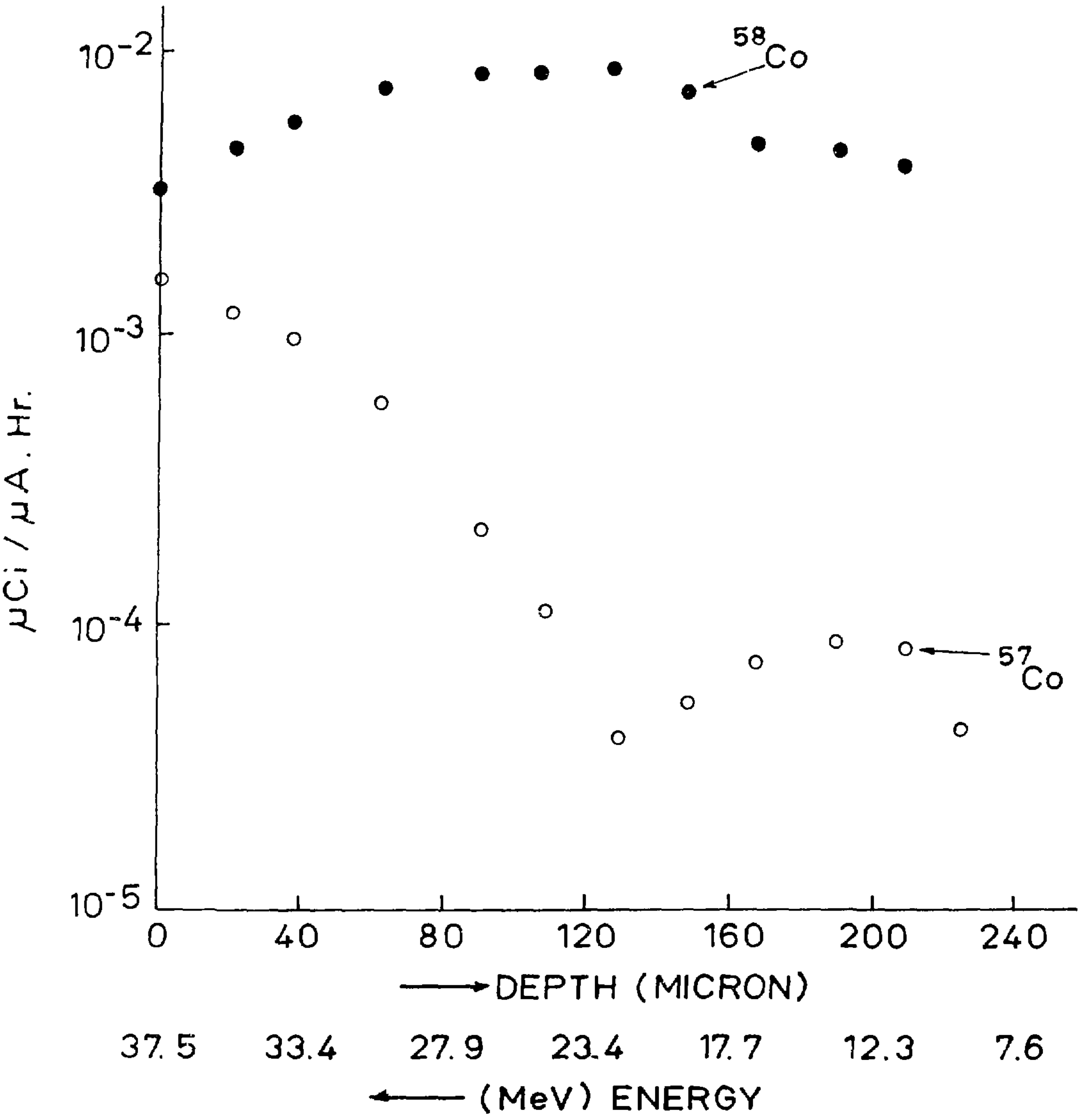
D.P.Chowdhary, S.Gangadharan

Standard foil activation measurements have been carried out with Fe, Ni, the principal compo nents of alloys of materials used in the-system investigated(1). 2.5 μ thick foils of Ni and 0.16 μ thick Fe depo sited on 25.4 μ thick Al backings have been used as targets with aluminium foils serving as spacer cum energy degrader. Irradiations were carried out with 40 Me V alpha and standard high resolution gamma ray spectrometric techniques have been used for quantitating the nuclides. Figures summarise the yield data for two nuclides with "convenient" halflives.

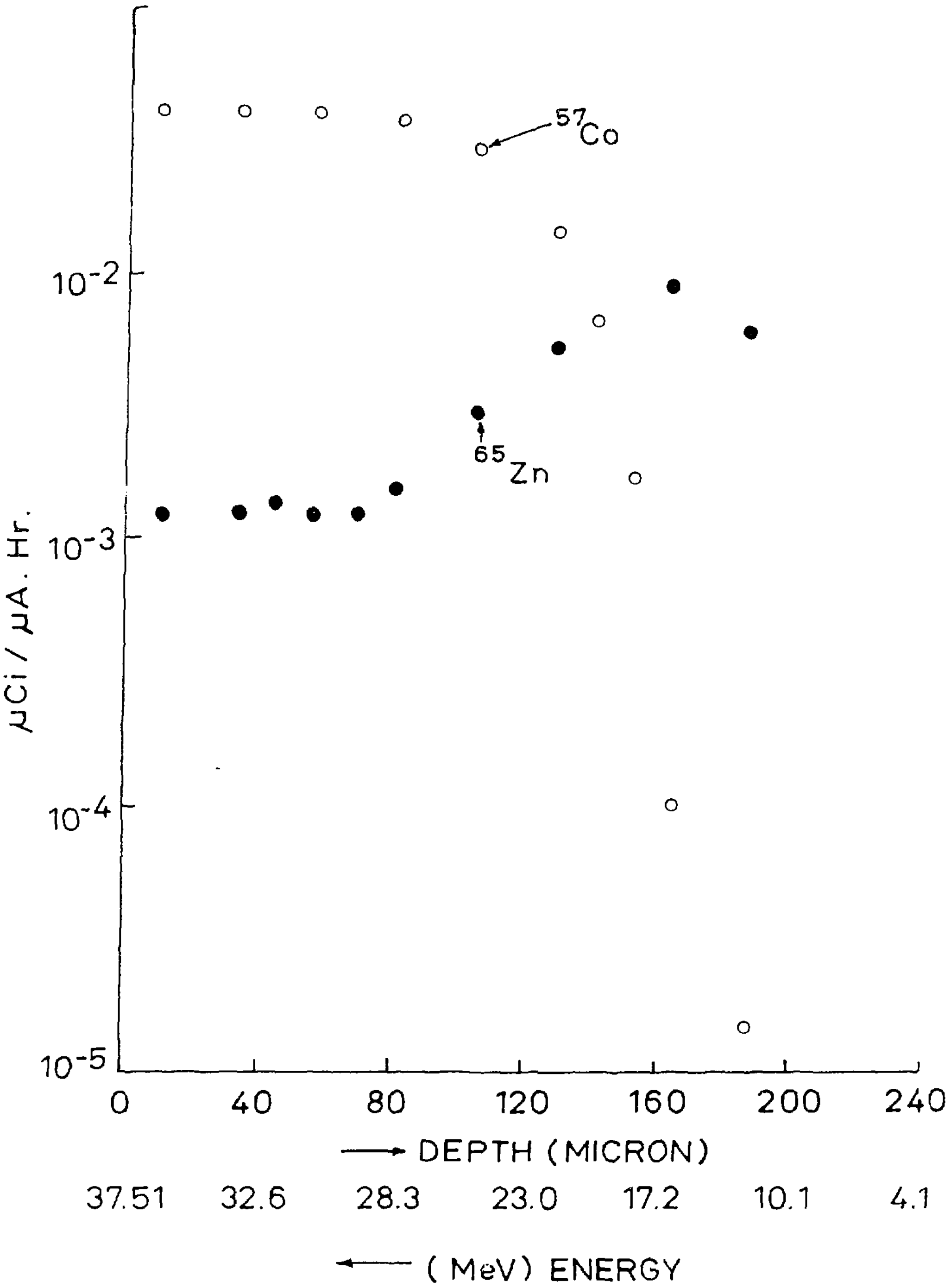
(1) STUDY OF WEAR BETWEEN PISTON RING AND CYLINDER HOUSING OF AN INTERNAL COMBUSTION ENGINE BY THIN LAYER ACTIVATION TECHNIQUE.

D.P.Chowdhury, Jayanta Chaudhuri, V.S.Raju, Alok Chakraborti, B.B.Bhattacharjee and S. Gangadharan

submitted for publication.



YIELD CURVES - Fe TARGET



YIELD CURVES - Ni TARGET

MEASUREMENT AND ANALYSIS OF Ta(α,4n)Re REACTION

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Alpha induced reaction on 181-Ta (α,4n) 181-Re was investigated from threshold to 60-MeV using stacked foil technique. The excitation function was compared with calculations considering equilibrium as well as pre-equilibrium reaction according to hybrid model of Blann using Code Overlaid Alice. The agreement between theory and experiment is good.

The stacked of commercially supplied foiled were irradiated in especially constructed chambers. The beam spots on the targets was limited to 5mm by using 10cm long collimator in front of targets stacks of about 20 foils with thickness $\sim$ 25μm were exposed to the external α-beam from VECC. The beam on target was kept between 0.5 to 1 μA. In front of each stack a 75 μm thick Al foil was placed additionally for flux monitoring.

The nuclear data necessary for the evaluation of the cross-sections for 181-Re are as follows:
Half-life: 19.97 hours; E_γ :361+366 KeV; I_a:12.3, 57.0%
Q-value:-31.75 MeV. The γ-ray spectra emitted by the activated foils were measured with Ge(Li)-detector.

EXPERIMENTAL RESULTS: Expt. and Theo. Cross-Section are presented in fig.1. The agreement is good. Experimental Cross-Section for 181-Ta (α,4n) 181-Re Reaction:

E (MeV)	Cross-Section(mb)
57.5-55.2	325.2
55.2-52.8	426.3
52.8-50.3	598.4
50.3-47.7	815.1
47.7-45.1	988.6
45.1-42.4	940.6
42.4-39.4	745.6
39.4-36.4	387.5
36.4-33.2	87.9

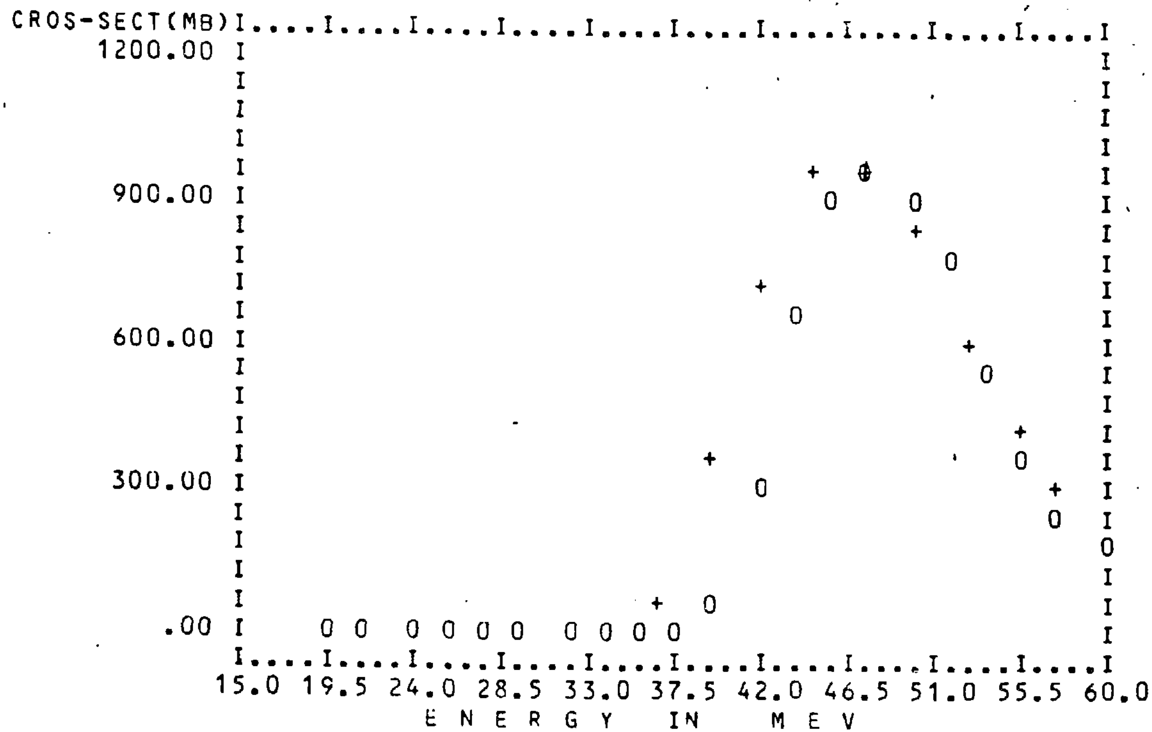

Fig 1 181-Ta(Alpha,4N)181-Re Ex. Fn.(O = THEO. PTS.)

YSCALE= .60E+02 MB XSCALE= .90E+00 MEV

FIG.1.

PROTON INDUCED FISSION OF ^{235}U AT EXTREME SUB-BARRIER ENERGIES

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Recently we have reported measurements of the proton induced fission cross-section of ^{235}U and ^{238}U at extreme sub-barrier energies /1/. The observed excitation function showed a pronounced shelf-like structure below 4 MeV for both targets. Fission in this region could either be that of the compound nucleus formed after projectile capture or of certain low lying target states following coulomb excitation. The former process involves penetrability of the coulomb barier while the latter of the fission barrier. To experimentally distinguish between these possibilites we have carried out new measurements of the fission cross-section for $P + {}^{232}Th$ and $\alpha + {}^{235}U$ and repeated measurements for $p + {}^{235}U$ at projectile energies bwlow 4 MeV using the method described in reference /1/.

The measured fission cross-sections are shown in the figures together with results at higher energies reported by other groups /2-5/. The abrupt change in the slope of the fission excitation function below 4 MeV observed for $p + {}^{235}U$ is not seen in the case of $p + {}^{232}Th$. In $\alpha + {}^{235}U$ below 4 MeV, measured values are many orders of magnitude larger than the reaction cross-section estimated by optical model calculations (Shown as continuous lines).

From barrier penetrability conderations, the compound nucleus formation cross-section for $\alpha + {}^{235}U$ is expected to be several orders of magnitude smaller than for $p + {}^{235}U$ at 3.5 MeV projectile energy (Epr). The measured fission cross-sections, however, are quite comparable in magnitude. It appears unlikely therefore that the observed fission cross-section for $p + {}^{235}U$ below 4 MeV is due to compound nucleus formation.

For Epr below 4 MeV, coulomb excitation of low lying levels in the target has cross-sections of the order of millibarns. The ratio of the calculated cross-section for coulomb excitation of a 100 KeV state in ^{235}U by protons to that by alpha particles at Epr=3.5 MeV is comparable to the ratio of the corresponding measured fission cross-sections. However, the penetrability of the fission barrier for the coulomb excited states is negligible unless the potential energy surface has a shallow pocket at high deformations. In such a situation fission from these states would be greatly enhanced by coupling to states in this pocket. Such a feature ispredicted by the calculations for high Z nuclides /6/. The observed shelf-like structure in the fission corss-section of p + 235 U could therefore be attributed to the broad shape of the coulomb excitation function for the relevant low lying target states. For Th-232 the calculations of reference /6/ do not indicate any potential pocket at high deformations. This is consistent with the absence of a shelf structure in the measured p + ^{232}Th fission data.

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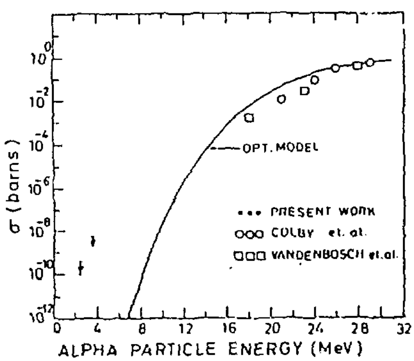

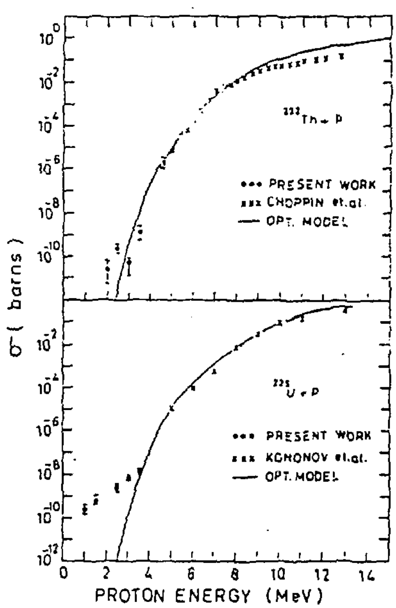

STATUS OF ACTIVITIES UNDERWAY ON EVALUATIONS OF THORIUM NUCLEAR DATA

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As a part of nuclear data evaluation for ^{232}Th- ^{233}U fuel cycle, following work was carried out.

(a) Recently reported neutron radiative capture cross section of Th-232 measurements in the energy range 0.1 to 1.2 MeV are compared with the calculations based on the statistical model Hauser-Feshback theory using the spherical optical model transmission coefficients and simple Fermi gas level density formula. The calculations are in good agreement with the recent experimental data, reproducing both the absolute magnitude and the shape exhibited by the excitation function. The results of this comparative study can be used for improving the evaluation of the neutron radiative capture cross section of Th-232.

This work was published as a BARC-1353 and INDC(IND)-038/L report (1987), Ref.1.

(b) The evaluation of the energy dependent experimental data for the average number of prompt neutrons, $\overline{\nu}_p$, for the neutron induced fission of Th-232 in the energy range from 1-20 MeV is nearing completion. The evaluation takes into account not only the actual numerical data on $\overline{\nu}_p(E_n)$ but also of certain physical concepts based on the energy balance in nuclear fission. The energy dependence of $\overline{\nu}_p$ is represented by two spline fitted curves because of the anomalous behaviour near threshold and multiple chance fission which introduces a non-linear dependence on E_n. Data are renormalised wherever necessary to the latest recommended value of (3.757) for $\overline{\nu}_p$ spontaneous fission of Cf-252. The present evaluation is compared with the existing ones. Recommended values of $\overline{\nu}_p(E_n)$ are given over the energy range 1-20 MeV.

This work was done with M.K. Mehta.

1. H.M. Jain, S. Kailas, "Neutron Radiative Caputre Cross-Section of 232-Th in the energy range 0.1 to 1.2 MeV".

NUCLEAR DATA ACTIVITIES OF NUCLEAR CHEMISTRY SECTION

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Nuclear data activities of Nuclear Chemistry Section have been carried out under the following categories:

1. Nuclear Fission Studies
   a) Charge Distribution
   b) Mass Distribution
   c) Angular Momentum

2. Nuclear Spectroscopy

   Gamma-ray Abundance Measurements

3. Theoretical

1) Nuclear Fission Studies

a) The charge distribution studies in SF as well as neutron and helium ion induced fission of actinides have been carried out to arrive at the width of the distribution, most probable charge and mass by determining fractional independent yields and fractional cumulative yields of different fission products and are presented in Tables 1 to 9. The alpha induced fission data is given in Table 5.

b) The mass yield data in 28.5 MeV α-induced fission of ^{232}Th has been reported in Table-10.

c) The angular momentum studies have been carried out to arrive at the scission configuration and to see the effect of nuclear structure, odd-even effect, presence of deformed shell on fragment angular momenta of the fission fragments in low energy fission by determining the isomer cross-section ratios for fission products. The data are presented in Tables 11 to 17.

The data on angular momentum studies in alpha induced fission at various energies of ^{238}U and ^{232}Th are presented in Table-15 to

2) Nuclear Spectroscopy

The measurement of gamma-ray abundance is presented in Table-18.

3) Theoretical

The data on the correlation between fractional independent yields and neutron to proton ratio of the fission products in low energy fission have been presented in Tables 19 and 20.

Table-1 Cumulative yields of short-lived Ruthenium isotopes in $^{241}Pu(n,f)$

A	Cumulative yield (%)	Chain yield (%)	Chain yield (Rider)* (%)
107	4.88 ± 0.04	4.935	4.86 ± 0.410
108	3.89 ± 0.31	4.078	3.896 ± 0.310
109	2.73 ± 0.01	3.142	2.922 ± 0.130

*NEDU-12154-3(C) (1981)

A.G.C. Nair, A. Goswami, S.K. Das, B.S. Tomar, B.K. Srivastava, Satya Prakash and M.V. Ramaniah,
Radiochemistry and Radiation Chem. Symposium, Tirupati, 1986.

Table-2 Independent yields of Iodine with relevant nuclear data in ^{245}Cm

S.No.	Nuclide	Independent yield
1	^{131}I	0.040 ± 0.012
2	$^{132}I^{m}$	–
	$^{132}I^{g}$	0.056 ± 0.011@
3.	^{133}I	0.235 ± 0.020
4.	^{134}I	0.218 ± 0.026@
5.	^{135}I	1*

@Total yield of both the isomers.

*Standard value

A.V.R. Reddy, S.M. Deshmukh, P.P. Burte, S.B. Manohar, Satya Prakash and M.V. Ramaniah,
Radiochemistry and Radiation Chem. Symposium, Tirupati, 1986.

Table - 3 Cumulative yields of Tellurium isotopes in ^{245}Cm

Nuclide	Cumulative yield
^{131}Te	0.418 ± 0.12
^{132}Te	0.731 ± 0.11
^{133}Te	0.684 ± 0.20
^{134}Te	0.693 ± 0.20

A.V.R. Reddy, S.M. Deshmukh, P.P. Burte, S.B. Manohar, Satya Prakash and M.V. Ramaniah, Radiochemistry and Radiation Chemistry Symposium, Tirupati, 1986.

Table - 4 Systematics of isotopic yield distribution of Iodine in different fissioning systems

Fissioning system	Width of the distribution	Most probable mass	Elemental yield
$^{233}U(n_{th},f)$	1.20 ± 0.12	134.60	10.56*
$^{235}U(n_{th},f)$	1.21 ± 0.10	135.90	15.34*
$^{237}Np(n_{th},f)$	1.50 ± 0.10	134.44	10.84
$^{239}Pu(n_{th},f)$	1.27 ± 0.05	135.20	16.63*
$^{241}Pu(n_{th},f)$	1.40 ± 0.10	135.65	12.65
$^{241}Am(n_{\gamma},f)$	1.39 ± 0.10	134.15	7.50
$^{245}Cm(n_{th},f)$	1.50 ± 0.20	134.57	11.90
$^{252}Cf(SF)$	1.61 ± 0.16	135.75	8.4

*Nucl. Phys. A 177, 337 (1971)

A.V.R. Reddy, S.M. Deshmukh, P.P. Burte, S.B. Manohar, Satya Prakash and M.V. Ramaniah, Radiochemistry and Radiation Chem. Symposium, Tirupati, 1986.

Table - 5 Most probable charge Zp for the fission products in the α -particle (30 MeV) induced fission of ^{232}Th

Nuclide	Z	Zp	Z-Zp	Determined FCY
^{135}I	53	53.18	-0.18	0.766 ± 0.02
^{138}Xe	54	54.30	-0.30	0.813 ± 0.03
^{140}Ba	56	55.06	+0.94	0.991 ± 0.004

A. Ramaswami, B.K. Srivastava, S.M. Sahakundu, S.B. Manohar, Satya Prakash and M.V. Ramaniah,
J. of Radioanal. and Nucl. Chem. Articles, Vol. 102, No. 2 (1986), 499-506.

Table -6 Isotopic yield distribution of Technetium isotopes in the thermal neutron induced fission of ^{241}Pu

Fissioning system	Y_Z (%)
$^{235}U(n_{th},f)$	0.092 ± 0.024*
$^{241}Pu(n_{th},f)$	7.62 ± 0.21
$^{252}Cf(SF)$	16.90 ± 2.09*

*Phys. Rev. C. 33, 969 (1986).

B.K. Srivastava, A. Goswami, A.G.C. Nair, B.S. Tomar, S.K. Das, S.B. Manohar, Satya Prakash and M.V. Ramaniah,
Nucl. Phys. Symp., Waltair, 1986.

Table - 7 Fractional cumulative yields of ^{91}Sr, ^{92}Sr in different fissioning systems

Fissioning systems	Z_F^2 / A_F	F. C. Y. ^{91}Sr	F. C. Y. ^{92}Sr
^{235}U	35.864	-	0.9987 ± 0.0002
^{233}U	36.171	0.981 ± 0.018	0.973 ± 0.013
^{241}Pu	36.512	0.965 ± 0.032	0.929 ± 0.036

H. Naik, S.P. Dange, T. Datta, Satya Prakash and M.V. Ramaniah, Radiochimica Acta 40, 175 (1986).

Table - 8 Fractional independent yield of Tc isotopes in the thermal neutron induced fission of ^{239}Pu

Mass	FIY	Y_A	$Y_I(A,Z)$	Ref.
101	0.0023 ± 0.0015	5.95 ± 0.08	0.014 ± 0.009	This work
102	-	-	0.050 ± 0.025	Interpolated
103	0.0346 ± 0.015	6.95 ± 0.14	0.241 ± 0.097	This work
104	0.090 ± 0.014	5.96 ± 0.12	0.536 ± 0.083	This work
	0.077 ± 0.012	-	-	*
105	0.195 ± 0.045	5.57 ± 0.11	1.086 ± 0.251	This work
	0.264 ± 0.021	-	-	*

*J. Inorg. Nucl. Chem. 43, 877 (1981)

A. Srivastava, A. Goswami, B.K. Srivastava, A.G.C. Nair, S.B. Manohar, Satya Prakash and M.V. Ramaniah,
Phys. Rev. C 33, No. 3, 969 (1986).

Table -9 Fractional cumulative yield in neutron induced fission of ^{237}Np

Nuclide	Zp	FCY
^{134}Te	52.29	0.589 ± 0.026
^{135}I	52.73	0.916 ± 0.14
^{135}Xe	53.96	0.885 ± 0.084

A. Ramaswami, S.S. Rattan, N. Chakravarti, R.J. Singh, S.B. Manohar and Satya Prakash,
Radiochimica Acta (In press)

Table -10 Fission yield data in 28.5 MeV Helium ion induced fission of ^{232}Th

Sr.No.	Fission Product	Chain yield %	Sr.No.	Fission product	Chain yield %
1.	^{87}Kr	2.01 ± 0.15	13.	^{115}Cd	1.40 ± 0.13
2.	^{88}Kr	2.71 ± 0.19	14.	^{127}Sb	1.95 ± 0.12
3.	^{91}Sr	4.29 ± 0.29	15.	^{129}Sb	3.07 ± 0.44
4.	^{92}Sr	3.98 ± 0.39	16.	^{131}I	4.27 ± 0.13
5.	^{93}Y	3.94 ± 0.16	17.	^{132}Te	5.50 ± 0.22
6.	^{97}Zr	4.47 ± 0.18	18.	^{133}I	5.28 ± 0.68
7.	^{99}Mo	5.04 ± 0.15	19.	^{135}I	5.51 ± 0.29
8.	^{103}Ru	3.17 ± 0.20	20.	^{139}Ba	5.11 ± 0.02
9.	^{105}Ru	2.47 ± 0.05	21.	^{140}Ba	5.10 ± 0.16
10.	^{111}Ag	2.25 ± 0.25	22.	^{141}Ce	4.81 ± 0.10
11.	^{112}Ag	1.36 ± 0.09	23.	^{142}La	2.57 ± 0.13
12.	^{113}Ag	1.55 ± 0.19	24.	^{143}Ce	2.77 ± 0.24

R. Guin, S.M. Sahakundu, S.B. Manohar, Satya Prakash and M.V. Ramaniah, Radiochimica Acta, 1986. (In press).

Table - 11 Comparison of angular momenta of fragments corresponding to ^{134}I in various fissioning nuclides

Fissioning Nuclide	FCY of ^{134}Te	$Y_m/(Y_m + Y_g)$ ^{134}I	Angular Momentum B($\hbar$)	Neutron Number (N_c)
^{234}U	0.669 ± 0.020	0.429 ± 0.028	8.1 ± 0.6	60
^{236}U	0.886 ± 0.010	0.412 ± 0.046	7.8 ± 0.9	62
^{240}Pu	0.664 ± 0.020	0.394 ± 0.047	7.5 ± 0.8	64
^{242}Pu	0.655 ± 0.016	0.362 ± 0.032	7.0 ± 0.5	66

S.P. Dange, H. Naik, T. Datta, A.V.R. Reddy, Satya Prakash and M.V. Ramaniah,
Radiochimica Acta 39, 127 (1986)

Table - 12 Fragment angular momentum in $^{252}Cf(SF)$

Fission Product	Independent Isomer yield ratio	RMS Angular momentum B ($\hbar$)
$^{111}Pd^{m,g}$	0.586 ± 0.070	8.8 ± 1.5
$^{131}Te^{m,g}$	0.503 ± 0.060	5.6 ± 1.0
$^{133}Te^{m,g}$	0.546 ± 0.071	6.1 ± 1.1
$^{134}I^{m,g}$	0.549 ± 0.066	11.5 ± 1.1
$^{138}Cs^{m,g}$	0.582 ± 0.068	9.8 ± 1.2

T. Datta, S.P. Dange, S.K. Das, Satya Prakash and M.V. Ramaniah,
Z physik A Atomic Nuclei 324, 81 (1986).

Table -13 Fragment angular momenta in thermal neutron induced fission of ^{241}Pu

Fission Product	Independent Isomer yield ratio	R.M.S. Angular momentum B ($\hbar$)
$^{131}Te^{m,g}$	0.526 $\pm$ 0.054	5.80 $\pm$ 1.10
$^{132}I^{m,g}$	0.450 $\pm$ 0.024	8.85 $\pm$ 0.65
$^{133}Te^{m,g}$	0.536 $\pm$ 0.075	5.95 $\pm$ 1.20
$^{134}I^{m,g}$	0.362 $\pm$ 0.032	7.01 $\pm$ 0.50

S.P. Danye, H. Naik, T. Datta, Satya Prakash and M.V.Ramaniah, J. Radioanal. Nucl. Chem. Letters (In press)

Table -14 Data on Isomer yield ratios and angular momenta

Fissioning system	Excitation energy (MeV)	Initial $\langle I \rangle$ $\hbar$	Isomeric yield ratio	Fragment J ($\hbar$)
$^{241}Pu(n,f)$	6.2	4-5	0.53 $\pm$ 0.08	8.1 $\pm$ 1.2
$^{238}U(\alpha,f)$	23.7	9.5	0.76 $\pm$ 0.08	13.3 $\pm$ 1.3

A. Goswami, S.K. Das, B.S. Tomar, B.K. Srivastava, T. Datta, Satya Prakash and M.V. Ramaniah,
Z. physik A Atomic Nuclei (In press)

Table-15 Independent isomeric yield ratios and fragments' rms angular momenta

Target	E_α	Fission product	Z_p^*	Precursor FCY	Yield Ratio(F)	$J_{RMS}(\hbar)$
^{232}Th	40.0	^{131}Te	52.02	0.23	0.506 ± 0.061	5.9 ± 1.0
		^{133}Te	52.75	0.04	0.632 ± 0.070	7.9 ± 1.2
^{238}U	40.0	^{131}Te	51.96	0.26	0.730 ± 0.061	7.2 ± 0.6
		^{133}Te	52.70	0.05	0.634 ± 0.041	8.0 ± 0.8

T. Datta, S.P. Dange, Satya Prakash and M.V. Ramaniah,
Z. Physik A Atomic Nuclei (communicated)

Table-16 Comparison of angular momentum of fission fragment corresponding to ^{132}I in various fissioning nuclei

Fissioning Nuclei	C.Y. of ^{132}Te	$Y_m/(Y_m + Y_g)$ of ^{132}I	Angular Momentum B (ħ)	Neutron Number Nc
^{240}Pu	0.052*	0.403 ± 0.037	7.8 ± 0.6	66
^{242}Pu	0.697 ± 0.013	0.450 ± 0.024	8.85 ± 0.65	68
^{246}Cm	0.716 ± 0.019	0.482 ± 0.038	9.7 ± 1.0	70

*H. Ihara et al UNDC FP Decay and Yield Data JAERI-M-9715 (1981)

H. Naik, S.P. Dange, T. Datta, Satya Prakash and M.V. Ramaniah,
Radiochemistry and Radiation Chem. Symposium, Tirupati, 1986.

Table -17 Isomer ratios m/g for the residues ^{197}Hg and ^{196}Au at 44 and 49 MeV ^{4}He ion bombarding energy

Residual Nuclide	Spin Parity	Ejectile Nucleon Number	m/g at Energies MeV (Lab) 44	49
^{197m}Hg	$13/2^{+}$	4	0.02	0.12
^{197g}Hg	$1/2^{-}$			
^{196m}Au	12^{-}	5	0.01	0.05
^{196g}Au	2^{-}			

N. Chakravarti, R.J. Singh, S.S. Rattan, A. Ramaswami, S.M. Sahakundu, Satya Prakash and M.V. Ramaniah,
Radiochemistry and Radiation Chem. Symposium, Tirupati, 1986.

Table -18 Absolute abundance of 434 KeV gamma line of ^{108}Rh and its branching fraction from ^{108}Ru

Abundance of the 434 KeV line is 31.5 ± 1.0%.

The decay of ^{108}Ru to ^{108m}Rh is negligible.

S.K. Das, A.G.C. Nair, B.K. Srivastava, Satya Prakash and M.V. Ramaniah,
Radiochemistry and Radiation Chem. Symposium, Tirupati, 1986.

Table-19 $(N/Z)_p$ and $\sigma N/Z$ for various fissioning nuclei

Fission Products	$(N/Z)_p$	$\sigma N/Z$	$(N/Z)_f$	$\Delta N/Z$
^{235}U	--	-	1.538	
Light	1.487	0.040		-0.051
Heavy	1.560	0.025		+0.022
^{233}U			1.516	
Light	1.465	0.040		-0.051
Heavy	1.540	0.020		+0.024
^{239}Pu			1.523	
Light	1.475	0.042		-0.048
Heavy	1.542	0.020		+0.019
^{241}Pu			1.543	
Light	1.495	0.040		-0.048
Heavy	1.560	0.025		+0.017
^{252}Cf			1.533	
Light	1.480	0.040		-0.052
Heavy	1.550	0.025		+0.018

Table-20 Most probable and average values of $\bar{A}/\bar{Z}$ for light and heavy fission products in different fissioning systems

Nuclei	$\bar{A}_L$	$\bar{Z}_H$	$\bar{A}_L/\bar{Z}_H$	$(\bar{A}/\bar{Z})_p$	$\bar{A}_H$	$\bar{Z}_H$	$(\bar{A}/\bar{Z})_H$	$(\bar{A}/\bar{Z})_p$
^{233}U	99.30	37.71	2.474	2.465	138.20	54.29	2.540	2.540
^{235}U	94.90	37.95	2.500	2.487	138.60	54.05	2.564	2.560
^{239}Pu	98.90	39.90	2.478	2.475	138.10	54.10	2.552	2.542
^{252}Cf	106.10	42.26	2.510	2.480	142.10	55.74	2.549	2.550

A. Goswami, B.K. Srivastava, A. Srivastava, S.B. Manohar, Satya Prakash and M.V. Ramaniah,
Pramana 26, 179 (1986).

ANALYSIS OF U-233 IRRADIATION EXPERIMENT IN RAPSODIE EXPERIMENTAL FAST REACTOR

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This report summarises results of additional calculations performed since our earlier report (Gopalakrishnan and Ganesan, 1986) for analysis of U-233 irradiation experiment conducted in RAPSODIE reactor (Cricchio et al., 1983). In Table 1, we present the fission and capture cross sections calculated using the four different multigroup sets and also the data of (Meadows, 1983) for fission cross section. The KEDAK file based calculated value was taken from reference (Cricchio et al., 1983) and reproduced in Table 1 by us. It is interesting to see that the "C/E" for fission is close to unity in the case of French set and 0.93 and 0.95 respectively for ENDL-84 and JENDL-2 based multigroup sets. The recent (Meadows, 1983) fission cross sections also give an effective fission cross section as seen from table 1 coinciding with that of ENDL-84. However, in the analysis of JEZEBEL-23 assembly the K-eff was (Ganesan et al., 1987) over-predicted by 3.76% by the French set and under-predicted by 3.2% by ENDF/B-IV based set. The reason was traced (Ganesan et al., 1987) to be mainly due to lower values in ENDF/B-IV and higher values in the most important groups in the French set for fission cross sections. It is interesting that the calculated values presented in Table 1 for effective one-group fission cross section in the TACO experiment for ENDL-84 and JENDL-2 based sets are in between those of the French set and the ENDF/B-IV based set. Thus, there is relative consistency in the "C/E" value of effective one-group fission cross sections of the French "TACO" experiment presented in Table 1 and of K-eff of JEZEBEL-23 assembly. It is interesting to note that the experimental value of fission cross section in Table 1 has an error of ± 6%. Thus a "C/E" of 0.95 is well within this error of 6%, thus making the analysis less effective. Unfortunately, therefore, this integral validation study cannot strictly claim to lead to any definite recommendation on U-233 fission or capture cross sections.

If one were to take the mean experimental value of fission cross sections for comparison with calculated values, then from the discussions presented here, we may be inclined to suggest that probably due to poor characterisation of neutron spectra the calculated one group cross sections may have a systematic error of about -4 to -5%. If this conclusion were to be accepted the effective one group values in Table 1 for fission should all be increased by about 4 to 5%. This suggestion may be further examined, if the current program of experiments underway in a group as mentioned by (Demeester et al., 1986) in the recent 1985 Santa Fe conference throws light on this aspect further. The experiments proposed by (Demeester et al., 1986) are expected to avoid the weaknesses of the "TACO" experiment by characterising the neutron spectrum accurately at the irradiation position.

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TABLE 1

COMPARISON OF INTEGRAL CROSS SECTIONS (IN BARNS) FOR U-233 IN RAPSODIE REACTOR

		FISSION	CAPTURE
Experimental values (E) ** (RAPSODIE)		2.31 ± 6%	0.155± 0.2%
Calculated values (C)			
KEDAK (Cricchio et al.,1983)		2.12	0.155
C/E		0.92	1.0
CADARACHE	IGCAR	2.28	0.182
C/E		0.99	1.17
ENDF/B-IV (Cricchio et al, 1983)		2.11	0.156
C/E		0.91	1.01
ENDL-84	IGCAR	2.195	0.164
C/E		0.95	1.06
JENDL-2	IGCAR	2.141	0.165
C/E		0.93	1.065
MEADOWS	IGCAR	2.196	-----
C/E		0.95	-----

**: The standard deviations for the experimental values were calculated (Cricchio et al., 1983) either from duplicate or triplicate capsule results.

INTERCOMPARISON OF BASIC DATA FILES FOR U-233 IN MULTIGROUP FORM

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The following three basic data files obtained from IAEA Nuclear Data Section (DayDay, 1984; Cullen and McLaughlin, 1985; Lemmel, 1987) represent the latest versions of the respective originating laboratories.

1.ENDL-84 (1984) basic evaluated data library (Howerton, 1984) of Lawrance Livermore Laboratory, (LLL), U.S.A.

2. ENDF/B-IV (1974) American basic evaluated data file (Garber et al., 1975) released by Brookhaven National Laboratory, U.S.A. (BNL)

3. The second version of the Japanese Evaluated Nuclear Data Library JENDL-2 (Asano et al., 1982; Kikuchi, 1984)

The pre-processing of these libraries were carried out at IGCAR to generate the temperature dependent point cross sections at variuos temperatures using the recent version of pre-processing and processing codes.

All the three basic data files JENDL-2, ENDF/B-IV and ENDL-84 were accurately processed and multigrouped. The experience for the pre-processing of JENDL-2 is shown in the flowchart given in Fig. 1.

Complete sets of intercomparison tables for $\langle\sigma_t\rangle$, $\langle\sigma_{tr}\rangle$, $\langle\sigma_c\rangle$, $\langle\sigma_f\rangle$, $\langle\nu\sigma_f\rangle$, $\langle\sigma_{in}\rangle$ and self-shielding factors are available (Ganesan, 1987) with the authors. The French set (Barre, 1969) which is already available in multigroup form at IGCAR has also been included in the intercomparison study.

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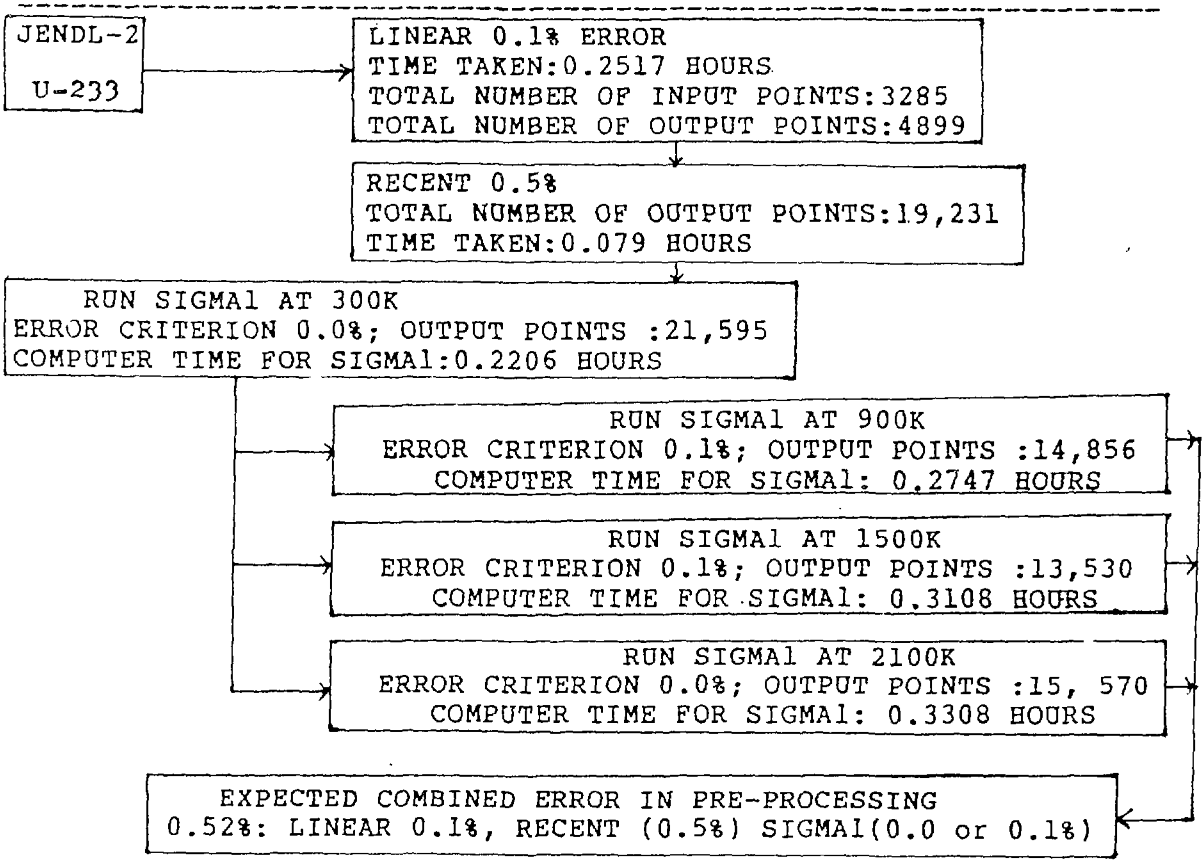

Fig. 1 Pre-processing experience for U-233 of JENDL-2 at Kalpakkam with Honeywell Bull Computer at Kalpakkam.

PROCESSING OF U-238 DATA FROM ENDF/B-IV WITH STRINGENT RESONANCE RECONSTRUCTION TOLERANCES

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Results of calculations in the IAEA Code Verification Project performed at Kalpakkam demonstrated (Ganesan et al., 1986, 1987) that a relative error of 20% in $\delta\tilde{\Sigma}_c$, the Doppler change in self-shielded capture cross sections can arise in the resolved resonance region from interpolation error of 1% in pre-processing. With the improvements carried out at IAEA by cullen, in his pre-processing code systems as discussed in a recent paper (Ganesan et al., 1987) the relative error in $\delta\tilde{\Sigma}_c$, can be kept to a value below 2% by limiting the net interpolation error to 0.5% in the current version of these codes. This will help to limit error in calculation of Doppler reactivity coefficient arising from interpolation error in pre-processing to below 2% (Ganesan et al., 1987).

The U-238 data was therefore re-pre-processed and the Kalpakkam multi roup set updated. The current state of art in pre-processing with 1986 version of pre-processing codes is illustrated in Fig. 1 for data of U-238 retrieved from ENDF/B-IV.

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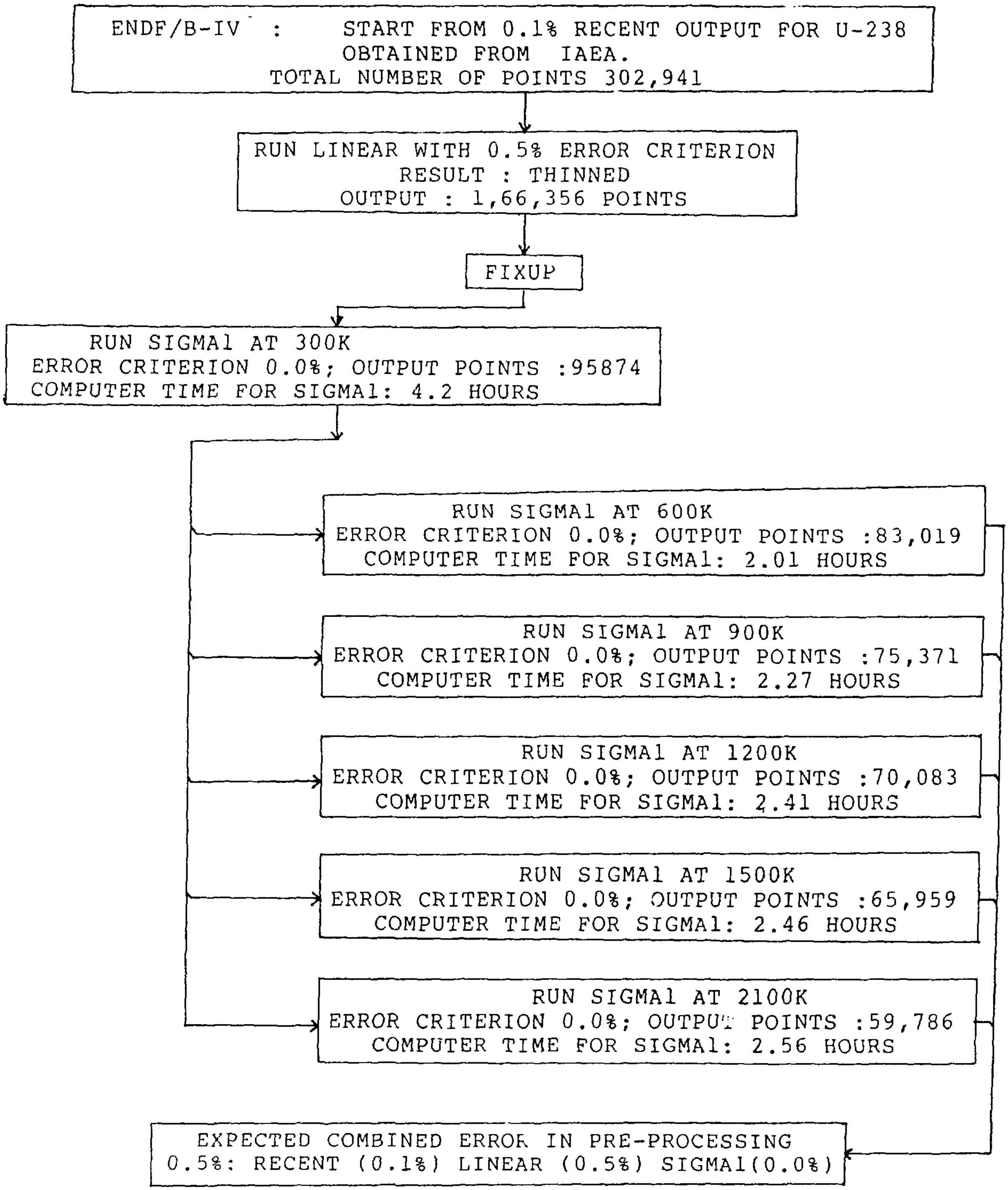

Fig. 1 PROCESSING OF U-238 DATA FROM ENDF/B-IV WITH STRINGENT RESONANCE RECONSTRUCTION TOLERANCES USING LATEST VERSION OF PROCESSING CODES AT KALPAKKAM USING HONEYWELL BULL COMPUTER

NUCLEAR DATA REQUIREMENTS FOR THE DEVELOPMENT OF ACCELERATOR BREEDER

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Following abstract is taken from Ref.1.

Considerable interest has recently been exhibited in the concept of using a 1-1.5 GeV proton beam for economically producing the fissile material. A practical realisation of the concept of accelerator breeding depends both on the evolution of a satisfactory accelerator and considerable engineering development. The nuclear data requirements for the design and operation of the accelerator breeder cover neutron energies upto 1.5 GeV for the blanket. The need for extending the energy range much beyond 20 MeV for the existing neutron-nuclear data bases such as ENDF/B used for fission reactor applications is recognized. The data requirements and status that are discussed are: the total number of neutrons emitted in the proton induced spallation process, neutron production cross sections by (n, xn) reactions, uncertainties in the spectra of neutrons emitted both in the cascade steps and in the evaporation steps, nuclear data requirements for calculations of heat generation in the spallation target, hydrogen and helium production cross sections in the structural materials comprising the blanket, production cross sections for spallation nuclides, data requirements for prediction of kinetic energies of spallation nuclei for assessment of radiation damage in the blanket. The conclusions are as follows. The existing data in the literature shows a spread of a factor of two for the neutron yield which directly affects the economics. The cross sections for production of spallation nuclides generally appear to be known with a factor of two uncertainty. The helium production cross sections are uncertain by a factor of two or more. Several examples of data uncertainties are given highlighting that for all neutron interaction cross sections the nuclear data is very sparse beyond 15 MeV for both natural uranium and thorium targets.

Reference

1. S. Ganesan, Paper accepted for presentation in the Seminar on Physics and Technology of Particle Accelerators and their Applications, Variable Energy Cyclotron Centre, Calcutta, India during Jan.29 - Feb.3, 1987.

NEW COMPARISONS OF INFINITE DILUTION CROSS SECTIONS, SELF SHIELDED CROSS SECTIONS AND THEIR DOPPLER CHANGES FOR TH-232 CALCULATED USING JENDL-2 AND ENDF/B-V (REVISION 2) FILES

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The resonance parameters in various data files for Th-232 do not agree with each other. The differences in resonance characteristics in two evaluated neutron cross section data files reflect as differences in infinite dilution cross sections and the associated self-shielding effects. The data in the two evaluated basic data files may be considered to represent mean values of two populations (or samples) of the ensemble. If the group constants of two data files for a given temperature and background dilution agree with each other, that is, there is no discrepancy, it does not necessarily mean that there is no error in the data. A systematic error may still exist and the effective group constants of two data files may differ from the true values. A comparison is nevertheless certainly helpful to identify possible problem areas in the resonance region.

In order to make sure that processing of basic data files do not introduce additional errors of significant amount only the processing codes that passed (Ganesan et al., 1987) the first, second and third rounds of the IAEA nuclear data processing code verification project (Cullen, 1985; Ganesan et al., 1986b; 1987) were used as shown in Fig.1.

Complete details of the comparison results are presented in (Ganesan, 1987).

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ENDF/B-V : LINEAR 0.1% ERROR; TIME TAKEN:0.0217 HOURS
TOTAL NUMBER OF POINTS:1996

↓

RECENT 0.5%; TOTAL NUMBER OF POINTS:2,51,399
TIME TAKEN:3.19 HOURS

↓

LINEAR 0.5%; TOTAL NUMBER OF POINTS:1,12,767
TIME TAKEN:0.407 HOURS

↓

RUN SIGMA1 AT 300K; ERROR CRITERION 0.0%;
OUTPUT POINTS :86,924; COMPUTER TIME FOR SIGMA1:2.49 HOURS

↓

RUN SIGMA1 AT 2100K; ERROR CRITERION 0.0%; OUTPUT POINTS :52,543
COMPUTER TIME FOR SIGMA1: 2.16 HOURS

EXPECTED COMBINED ERROR IN PRE-PROCESSING
0.73%:LINEAR 0.1%, RECENT (0.5%) LINEAR (0.5%) SIGMA1(0.0%)

JENDL-2 : LINEAR 0.1% ERROR; TIME TAKEN:0.017 HOURS
TOTAL NUMBER OF POINTS:3031

↓

RECENT 0.5%; TOTAL NUMBER OF POINTS:1,89,249
TIME TAKEN:1.8 HOURS

↓

RUN SIGMA1 AT 300K; ERROR CRITERION 0.0%;
OUTPUT POINTS :90,105; COMPUTER TIME FOR SIGMA1:3.98HOURS

↓

RUN SIGMA1 AT 900K; ERROR CRITERION 0.0%; OUTPUT POINTS :72,769
COMPUTER TIME FOR SIGMA1: 2.29 HOURS

↓

RUN SIGMA1 AT 2100K; ERROR CRITERION 0.0%; OUTPUT POINTS :57,869
COMPUTER TIME FOR SIGMA1: 2.67 HOURS

EXPECTED COMBINED ERROR IN PRE-PROCESSING
0.52%: LINEAR 0.1%, RECENT (0.5%) SIGMA1(0.0%)

REX2-86

↓

OUTPUT OF REX2-86
SELF-SHIELDED CROSS SECTIONS AT THE GIVEN TEMPERATURE

↓

PROGRAM COMREX2-87

↓

COMPARISON TABLES OF SELF-SHIELDED CROSS SECTIONS AND THEIR DOPPLER CHANGES FOR ALL DILUTION CROSS SECTIONS NOTE: REX3-86 IS USED IN PLACE OF REX2-86 FOR PROCESSING UNRESOLVED RESONANCE REGION

FIG. 1 CALCULATIONAL FLOWCHART DEVELOPED AT, IGCAR, KALAPKKAM FOR OBTAINING COMPARISON TABLES OF SELF-SHIELDED CROSS SECTIONS AND THEIR DOPPLER CHANGES FOR ALL DILUTION CROSS SECTIONS

DEVELOPMENT AND ADAPTATION OF COMPUTER CODES RELATED TO EVALUATION AND PROCESSING OF NUCLEAR DATA

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The details of the work done in the field of development and adaptation of computer codes related to nuclear data research at Kalpakkam are given below:

1. LINEAR-86: This code replaces the 1985 version of LINEAR. The code is in Fortran-77H and is compatible with ENDF/B-IV, V, VI formats.

2. RECENT-86: This code replaces the 1985 version, and, can handle the energy dependant scattering radius for the processing; it has compatibility with Fortran-77H version.

3. SIGMA1-86: This code is an improved Fortran-77H version.

4. FIXUP-86: This code which was obtained from IAEA replaces the earlier versions .

5. UNRESR: This is a part of NJOY system and it deals with generation of self-shielded cross sections in the unresolved resonance range. This module has been successfully adapted.

6. MODER: This is a part of NJOY system and helps the conversion of ENDF/B formatted mode to NJOY blocked binary mode.

7. NJOYMAIN: This is the main part of the NJOY system of modules. It consists of a set of utilities each performing a well-defined processing task. The IBM version of this code has been successfully adapated to our in-house computer.

8. COMREX2: This is an indigenously developed code for comparison of self-shielding factors and Doppler changes for any material and for any reaction.

9. RESENDD: This Japanese code adapted to our inhouse computer reconstructs resonance parameter data into pointwise cross sections, Doppler broadens and also handles Reich-Moore parameters and energy dependent scattering radius.

10. ENDFINFO: This will output a table of the MAT number,

symbol, number of energy regions, limits of resonance region, etc., of all the materials present in a neutron data library in the ENDF/B format.

11. TRUNK : This program outputs the data of an ENDF/B material within a specified energy region cutting off the remaining. The output follows ENDF/B conventions and can be processed by the pre-processing codes. This is useful to study the contribution of any particular energy region and has been developed for some specific research studies in data processing.

12. COPYENDF: This utility program can copy from a nuclear data library in ENDF/B format, data of any selected material(s) or any section(s).

13. ABAREX: This code adapted to our inhouse computer is a FORTRAN-77 version. The code was designed mainly for analysis and calculations of the elastic (including compound and shape-elastic parts) and inelastic (with excitation of separate levels) reaction cross sections and their angular distributions, as well as total, capture and fission cross sections in the energy region where it is possible to use the statistical model approach and where the charge-exchange reactions do not contribute substantially. The code includes an optical model subroutine for calculations of total, shape-elastic cross sections and neutron transmission co-efficients. Reference: P.A. Moldauer, Nuclear Theory for Applications, held at Trieste, 17 January - 10 February, 1978, IAEA-SMR-43, p.165 (1980), IAEA, Vienna.

14. COMPDEN: This indigenously developed code is useful for comparison of displacement damage cross sections as obtained from two different processing codes SPECTER and RECOIL.

15. SPECTER: This code was obtained from Dr. L.R. Greenwood of Argonne National Laboratory, U.S.A. This code facilitates damage calculation for any specified neutron radiation. The SPECTER code relies on master libraries of displacement cross sections recoil distributions and other nuclear data. SPECTER itself is relatively short program, however, the library files are rather extensive.

Six different pre-processing codes were received from Dr. L.R. Greenwood of Argonne National Laboratory for the SPECTER code. All these programs have been successfully commissioned.

SYSTEM CRITICALITY CONSIDERATIONS FOR U-233 METAL ASSEMBLY USING NEUTRON CROSS SECTION DATA FROM FOUR DIFFERENT SOURCES

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The critical assembly JEZEBEL-23 as a bare sphere of U(98.13 at/w% U-233) metal, is especially suited (BNL, 1983) for testing U-233 cross sections in the fission source energy range.

The reactor region cross sections were prepared using EFFCROSS code (Damiens and Ravier, 1967) and the one dimensional transport calculations were performed using DTF-IV code (Lathrop, 1965).The results are presented in Table 1.

Very interestingly both the recent files ENDL-84 and JENDL-2 libraries predict K-eff within 1%. It is interesting to note that the French set (1969) over-predicts K-eff by 3.76% whereas ENDF/B-IV based multigroup set under-predicts K-eff by as much as 3.2%. Thus a spread of nearly 6.94% exists in the calculated values of K-eff obtained from these two older files.

In the present analysis of JEZEBEL-23 critical assembly the most important groups contributing to capture and fission reaction rates are in 500 keV - 3 MeV energy region. From all the results of intercomparison (Ganesan, 1987) we conclude that the higher calculated value of K-eff obtained by the use of the French set is mainly explained by the fact that the French set has higher $\langle \bar{\nu} \sigma_f \rangle$ values. The lower value of K-eff calculated by ENDF/B-IV is explained to be mainly due to the lower value of $\langle \bar{\nu} \sigma_f \rangle$ in ENDF/B-IV.

Complete details of this study have been documented in reference (Ganesan, 1987).

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TABLE 1

SYSTEM CRITICALITY CONSIDERATIONS FOR U-233 METAL ASSEMBLY USING NEUTRON CROSS SECTION DATA FROM FOUR DIFFERENT SOURCES

Measured Eigen Value : 1.000 ± 0.001 (BNL, 1983)

Case	File Used For U-233	For Minor Isotopes U-234, U-235 and U-238	K-eff, Calculated
1	French (1969)	FRENCH	1.0376
2	French (1969)	ENDF/B-IV	1.0374
3	ENDF/B-IV	ENDF/B-IV	0.9682
4	ENDL-84	ENDF/B-IV	1.0072
5	JENDL-2	ENDF/B-IV	1.0008

BASIC EVALUATED DATA FILE
e.g. ENDF/B-IV
or
ENDL-84
or
JENDL-2

↓

LINEAR : LINEARIZE ENDF/B

↓

RECENT : RECONSTRUCT RESONANCE CROSS SECTIONS

↓

SIGMA1 at 300 K : DOPPLER BROADENING

↓

REX1, REX2, REX3 : MULTIGROUPING; SELF-SHIELDING FACTORS

↓

LCAT : FORMAT CONVERSION

↓

MULTIGROUP SET

↓

EFFCROSS ← INPUT FAST REACTOR COMPOSITION

↓

MIXTURE CROSS SECTIONS

↓

DTF-IV TRANSPORT CALCULATIONS ONE DIMENSIONAL SPHERICAL MODEL

↓

RESULT: Neutronic Parameters of fast reactor

Fig.1: CODE SYSTEM AND CALCULATIONAL FLOW CHART FOR NEUTRONIC STUDIES CALCULATIONS OF A FAST REACTOR SYSTEM AT IGCAR, KALPAKKAM, STARTING FROM BASIC EVALUATED DATA FILE, AS DEVELOPED AT IGCAR, KALPAKKAM.

KALPAKKAM'S PARTICIPATION IN THE IAEA NUCLEAR DATA PROCESSING CODE VERIFICATION PROJECT: DOPPLER BROADENING AND SELF-SHIELDING VERIFICATION PROBLEM

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For the second and third rounds of the IAEA cross section processing code verification project investigating the effects of self shielding and Doppler broadening it was decided to use the NEACRP U-238 problem. All participants are asked to use the ENDF/B-IV U-238 evaluation averaged over the energy range 2.0347 to 3.3546 keV with flat (constant in energy) spectrum and Bondarenko self shielding model. Results should be reported to the IAEA for 300 and 2100 K, for dilutions ( ) of 0, 1, 10, 10, 10 and 10 barns as well as the infinitely dilute cross section at each temperature; for example results, see (Ganesan et al., 1987). In addition to these results participants should state the intended accuracy of these results, e.g. state uncertainties introduced due to cross section from processing. By using this simple test problem where all participants start from the same evaluated data and no transport calculation is required, all differences in the results can be directly attributed to the effect of cross section processing.

Main results of our paticipation

During our participation in the project the codes that passed (Ganesan and Ramanadhan, 1984) the first round were used.

The initial results of Doppler broadening and self shielding calculations had inconsistencies and led to the discovery of errors in the original SIGMA1 method of Doppler broadening. Analysis of the errors found and improvements made by Cullen in Vienna in the SIGMA1 method are presented in (Ganesan et al., 1987). Improved results are presented in order to demonstrate that the new SIGMA1 method can produce results within required accuracies. Improved codes and procedures show lesser sensitivity of calculated self shielded cross sections and their Doppler changes to tolerance parameters used in pre-processing. This fact was again verified by running the improved code LINEAR/RECENT/GROUPIE or REX2 in Vienna and Kalpakkam and comparing the results. Discrepancies could be attributed to the way in which (i) the energy grid was chosen, (ii) additional points were introduced in the grid and, (iii) the data thinned subsequently, i.e. the process of generating the Doppler broadened cross sections by SIGMA1 code. The other possible causes are the SLBW representation leading to negative elastic and total cross sections, inadequacy of decimal places in the reconstructed grid and single precision treatment.

One of the important results presented in this study is that the <u>original</u> SIGMA1 method of numerically Doppler broadening as proposed by Cullen and Weisbin in 1976 has now been demonstrated to be inaccurate and not capable of producing results to within required accuracies. Fortunately, due to this study the SIGMA1 method has been significantly improved and the new SIGMA1 is now capable of producing results to within required accuracies. Although this study presents results based upon using only one code system it is important to realize that since the original SIGMA1 method is presently used in many cross section processing code systems the results of this study indicate that unless these other code systems are updated to include the new SIGMA1 method the results produced by these code systems could be very inaccurate.

Importance for correlated uncertainties

Another noteworthy result is the demonstration of the importance for correlated uncertainties.

Our results demonstrated that the actual uncertainty introduced due to cross section processing is consistently at least an order of magnitude less than the error predicted assuming that the uncertainties in the cross sections at the two temperatures are uncorrelated: i.e. we can see that the uncertainties are strongly correlated.

Guidelines for tolerances input to pre-processing codes:

The results of our participation in the project led to the guideline that where temperature dependent changes in the self shielded cross section are important the target accuracy of a maximum of 2% uncertainty in the Doppler change in the self-shielded cross section due to cross section processing can be achieved by using the recommendations to limit the uncertainty due to linearising and Doppler broadening to 0.1% and reconstruction to 0.5%.

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PROCESSING NEUTRON CROSS SECTION DATA FOR 91-PA-231

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The isotope 91-Pa-231 plays an important role in nuclear fuel cycles using thorium. Its formation in thorium fuel leads to one of the routes for production of 92-U-232 isotope. The prediction of the amount of 92-U-232 isotope is important as it leads to hard gamma ray emitters. The calculation of fuel activity in thorium systems and prediction of 92-U-232 content in irradiated thorium require nuclear data of 91-Pa-231, particularly the neutron capture cross sections. The criticality of systems made of this isotope is also of interest in thorium cycle studies and hence there is a need for generating complete multigroup data.

On a request from Dr. M. Srinivasan, Head, Neutron Physics Division of Bhabha Atomic Research Centre (BARC) (Srinivasan, 1987), for processed neutron cross section data for 91-Pa-231, a survey was made on the available data and evaluated nuclear data files wherein data for this actinide is available.

The following data are available in literature:

	EVALUATOR	REFERENCE	DATE	ENERGY REGION
1.	GARG	INDC(SEC)-61	1977	100 keV to 20 MeV
2.	Jary	CEA-N-2084	1979	Maxwell
3.	Vasiliu et al.	INDC(RUM)-11	1979	0.0 eV to 19 MeV
4.	Abagyan et al.	YK-1(40) 39	1981	Maxwell
5.	F.M. Mann	ENDF/B-V(Actinides) IAEA-NDS-13,Rev.5 distributed by H. D. Lemmel, May, 1986.	1985	10^{-5} eV to 20 MeV

The last one, namely the ENDF/B-V (Actinides) data library was chosen for the present purpose. This file gives for 91-Pa-231 (MAT number 8131), the neutron cross section data in the following way:

a.	10^{-5} eV to 14.3 eV	Resolved Resonance Parameters with floor corrections in the form of tabulated cross sections.
b.	14.3 eV to 1 keV	Unresolved Average Resonance Parameters with floor corrections.

c. 1 keV to 20 MeV — Tabulated cross sections vs energy.

Processing Steps:

The codes LINEAR, RECENT and REX-1 were used to pre-process and multigroup the data for this isotope. The LINEAR code was run with 0.1 % tolerance for converting all interpoltion schemes to linear-linear and the option to keep all evaluated data points was given. Processing by LINEAR is a pre-requisite for the code RECENT, which would abort if non-linear-linar (cross section vs energy) table is found. However, for this isotope (MAT number 8131), it was apparent after running LINEAR that the original tabulations themselves followed only linear-linear interpolation between tabulated energy points.

The output of the LINEAR code containing the resonance parameter data as they were in the evaluated data was processed by RECENT which reconstructs the resolved and unresolved resonance parameters into point data amenable to linear-linear interpolation. This code generated 1534 energy points in the resonance region. The data generated by RECENT was multigrouped using REX-1. The French 25 energy group structure which is employed in our neutronic calculations was used.

The complete multigroup data for 91-pa-231 is given in the form of tables in our internal report (Gopalakrishnan, Ramanadhan and Ganesan, 1987).

References:

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UNDERSTANDING THE EFFECT OF POORLY CHARACTERISED NEUTRON SPECTRUM ON STUDIES OF INTEGRAL VALIDATION OF CROSS SECTIONS

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The use of poorly characterised neutron spectrum at the irradiation position in the apparently simple and straight forward calculation of one-group spectrum averaged cross sections affects the interpretation of "C/E" values for one group effective cross sections in a very complicated way. It is very instructive to observe both from academic and practical angles some interesting features based on a simplified sensitivity methodology as follows in order to understand the influence of the presence of a systematic error in spectrum characterisation.

In the usual notation the spectrum averaged fission cross section is given by

$$\bar{\sigma}_f = \frac{\sum_{g=1}^{N} \langle \sigma_f \rangle_g \langle \phi \rangle_g}{\sum_{g=1}^{N} \langle \phi \rangle_g}$$

A change in $\bar{\sigma}$ denoted by $\Delta\bar{\sigma}$ can be written in the linear approximation as

$$\Delta \bar{\sigma}_f = \sum_{g=1}^{N} \frac{\partial \bar{\sigma}_f}{\partial \langle \phi \rangle_g} \Delta \langle \phi \rangle_g = \frac{1}{\sum_{g=1}^{N} \langle \phi \rangle_g} \sum_{g=1}^{N} \left[\langle \sigma_f \rangle_g - \bar{\sigma}_f \right] \Delta \langle \phi \rangle_g$$

Note that $\partial\bar{\sigma}/\partial\langle\phi\rangle_g$ is + ve for groups for which the fission cross section $\langle \sigma_f \rangle_g$ exceeds the one-group spectrum averaged cross section $\bar{\sigma}_f$. It is -ve for energy groups for which $\langle \sigma_f \rangle_g$ is less than $\bar{\sigma}_f$.

For the flux spectrum shown of TACO experiment (Cricchio et al.,) the relative flux in each of the groups in energy region 0.748 keV - 15.00 keV, is within 1.3%. It is easy to show based on the above considerations that a factor of 3 systematic underprediction for very small fluxes (<1%) in the lower energy region 0.748 keV-15.00 keV gives rise together a cumulative effect leading to an underprediction of $\bar{\sigma}_f$ by 5%! Remember: Larger errors in measurement of small relative fluxes are not uncommon. A combination of systematic errors such as a +20% error for fluxes in groups 1 to 6 and -60% error for fluxes in groups 7 to 18 will also give rise to about the same -5% error in

σ_f . A systematic error of around -6% in $\langle\sigma_f\rangle$ g for the most important groups g=3 to 8 again leads to about -5% error in $\bar{\sigma}_f$, as expected even when there is no error in $\langle\phi\rangle$g. Thus no unique inference is possible regarding errors in cross sections or fluxes from "C/E" values when the error in fluxes are just not known. Further the 'E' value has a large error of ± 6% in this particular TACO experiment and all the calculated values of $\bar{\sigma}$ for fission in principle were (Ganesan, 1987) within the band of ± 6%. Thus, in summary, the interpretations of an integral experiment such as TACO experiment where the error in "E" is large for $\bar{\sigma}_f$ and error in "C" cannot be inferred because of unspecified systematic errors in $\langle\phi\rangle$g is not obviously expected to lead to any unambiguous validation of cross sections for U-233.

Full details of the discussions are given in (Ganesan, 1987).

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NUMERICAL INVESTIGATION TO EXAMINE THE VALIDITY OF BONDARENKO DEFINITION OF SELF-SHIELDED CROSS SECTIONS

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The neutron spectrum in energy is significantly influenced by the presence of resonances in cross sections of any material of interest and of the surrounding materials in a mixture in a reactor assembly -- the influence usually known as "the self-shielding". In the well known Bondarenko method of obtaining spectrum weighted group average neutron cross sections in the resonance region, the cross sections of the surrounding materials are represented by a parameter called the background or the dilution cross section taken to be constant in energy, whereas in reality it is energy dependant. The "self-shielding factor" of a material k in energy group g for the dilution σ_0 is given in conventional notation:

$$f = \frac{\langle \sigma_{x,g,\sigma_0}^{k} \rangle}{\langle \sigma_{x,g,\sigma_0\to\infty}^{k} \rangle} = \frac{\int_{E_{g+1}}^{E_g} \frac{\sigma_x^k(E)S(E)dE}{\sigma_t^k(E)+\sigma_0} \Big/ \int_{E_{g+1}}^{E_g} \frac{S(E)dE}{\sigma_t^k(E)+\sigma_0}}{\int_{E_{g+1}}^{E_g} \sigma_x^k(E)\,S(E)dE \Big/ \int_{E_{g+1}}^{E_g} S(E)dE}$$

The present day target (Rowlands, 1981) of less than 1% accuracy (1% for U-238 capture and 0.5% for Pu-239 fission for instance) in self-shielding factors has motivated us to see the deviaton in f due to assumption of energy independence of σ_0 . Hence we did calculations for the ZPR-6-7 critical assembly and found large deviations with respect to the target accuracy recommended. This fact is demonstrated by results presented in Table 1 and Table 2.

Full details of this work and the results obtained were presented in the 6th National Symposium on Radiation Physics held in Kalpakkam in March, 1986.

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1. Rowlands J.L., (1981) in Proceedings of the Conference on Uranium and Plutonium Resonance Parmeters. INDC(NDS)-129/GJ, Cullen D.E. (Editor) p.11, International Atomic Energy Agency, Vienna.

Table 1

Comparison of Self Shielding Factors obtained Using Energy Independent and Energy Dependent Dilution. Reaction : Capture

Material : U-238 (Concentration in ZPR-6-7 = 0.00578 atoms/barn-cm)

Group	Group limits upper	Group limits lower	Unshielded cross section (barns)	Effective dilution (barns)	SSF using existing method (Fe)	SSF using present method (Fp)	Fe / Fp
16	3.36KeV	2.04KeV	1.365	170.0	0.801	0.833	0.962
17	2.04KeV	1.24KeV	1.762	51.1	0.519	0.542	0.958
18	1.24KeV	750eV	2.715	49.5	0.416	0.441	0.943
19	750 eV	455eV	3.541	49.0	0.322	0.358	0.899
20	455 eV	276eV	3.538	64.4	0.326	0.368	0.886
21	276 eV	101eV	14.56	53.84	0.111	0.118	0.941
22	101 eV	22.6eV	31.33	57.88	0.0682	0.071	0.961
23	22.6eV	3.06eV	132.5	63.84	0.0528	0.057	0.926

Table 2

Comparison of Self Shielding Factors obtained Using Energy Independent and Energy Dependent Dilution. Reaction : Fission

Material : Pu-239 (Concentration in ZPR-6-7 = 0.000887 atoms/barn-cm)

Group	Group limits upper	Group limits lower	Unshielded cross section (barns)	Effective dilution (barns)	SSF using existing method (Fe)	SSF using present method (Fp)	Fe / Fp
21	276 eV	101 eV	18.54	403.27	0.711	0.904	0.786
22	101 eV	22.6 eV	41.86	392.61	0.592	0.909	0.651
23	22.6eV	3.06 eV	80.92	398.55	0.486	0.823	0.591
24	3.06eV	0.414eV	23.65	403.29	0.864	0.838	1.03

Generation of Group Constants for Th-232 in WIMS Energy Group Structure

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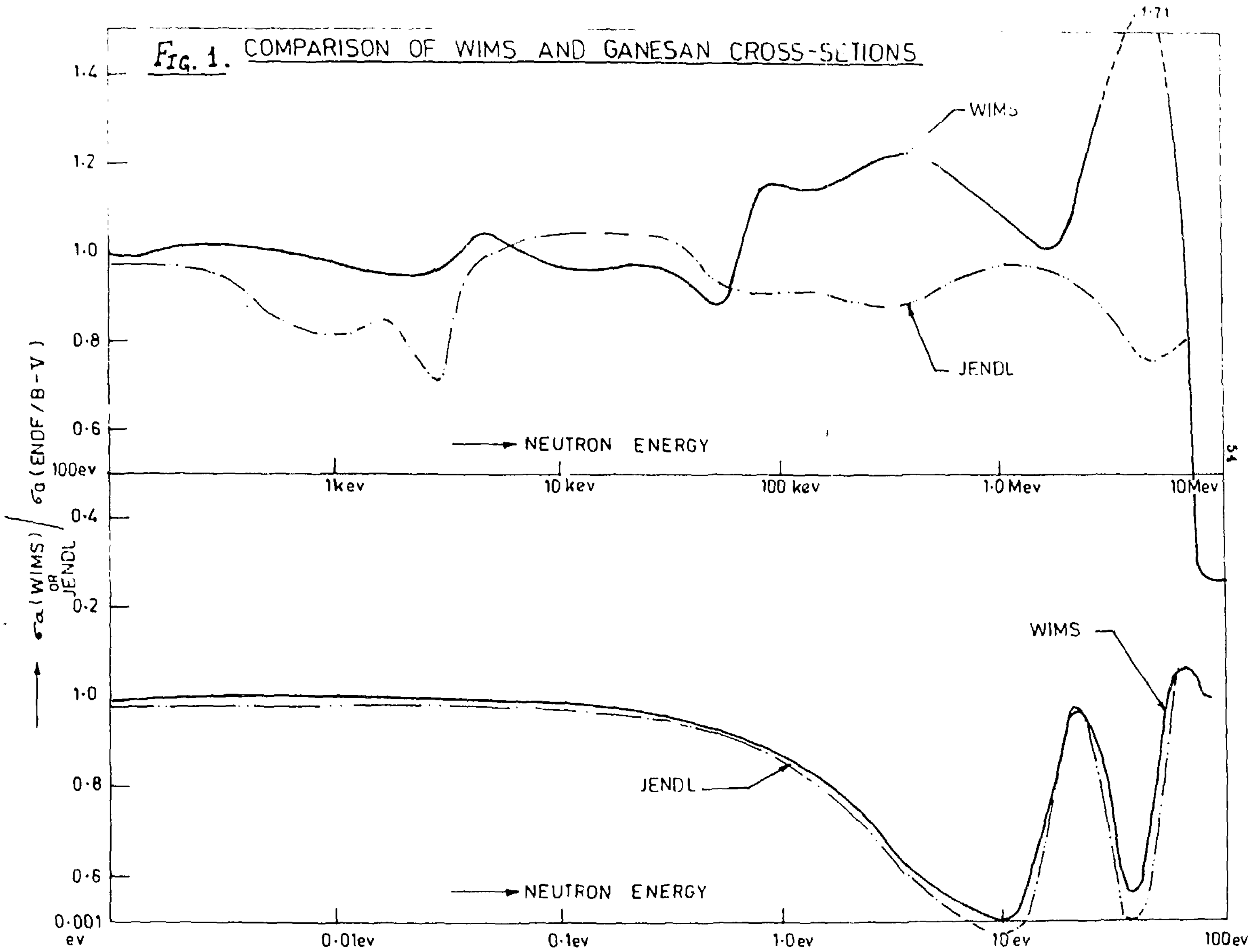
The WIMS cross-section library which is available in Reactor Engineering Division of BARC and which was obtained from the NEA, does not contain resonance tabulations for Th-232. Since these tabulations are absolutely essential for reactor work, we have started a collaborative effort between RED, BARC and the Nuclear Data Section, IGCAR to generate these cross-sections indigenously. For this purpose, we are using the most recent available basic evaluated cross-section data files and the processing code system developed by NDS, IGCAR.

Thorium cross-sections have been taken from JENDL-2 and also from ENDF/B-V. Preporcessed Doppler broadened point cross-sections for all types of neutron induced reactions are obtained from these. The sequence of calculations followed has been described in another paper.

So far we have generated WIMS 69 group cross-sections for Th-232 for two temperatures, viz., T = 0^{o}K and 300^{o}K. Two sets were generated, one from ENDF/B-V and the other from JENDL-2. Since the reasonnance tabulations are not yet complete, it has not been possible to validate the set against measured reactor physics parameters. However, in figure-1 we present the ratio of the ENDF/B-V generated cross-sections and the WIMS cross-sections to the JENDL-2 set. This gives an idea of the need for improved cross-sections. We have restricted ourselves to just one cross-section, σ_a.

FIG. 1. COMPARISON OF WIMS AND GANESAN CROSS-SECTIONS



CREATION AND AVAILABILITY OF KALPAKKAM MULTIGROUP CROSS SECTION SET

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The IGC nuclear data processing code system consisting of pre-processing codes LINEAR, RECENT, SIGMA1 and processing codes REX1-86, REX2-86 and REX3-86 is compatible with the internationally accepted format of the ENDF/B file and generates multigroup cross sections for use in fast reactor calculations.

Using our pre-processing and processing codes a 25 energy multigroup cross-section set has been created in the Nuclear Data Section for use in fast reactor calculations by processing the available basic evaluated neutron cross section data files in ENDF/B format. This multigroup cross section set is a 'non-adjusted' set, the term 'non-adjusted' implying that the set has not been modified by incorporation of information obtained from integral reactor experiments. Our studies indicate (Refer Report :IGCAR-77 for details) that the non-adjusted IGCAR multigroup cross-section set predicts neutronic parameters of critical assemblies simulating 500 MWe fast reactors, as accurately as non-adjusted multigroup cross-section sets of other laboratories.

The above mentioned 25 group IGCAR multigroup cross section set for fissile, fertile and structural isotopes/elements based on various libraries as mentioned in Table 1 has been created and tested by analysis of selected fast critical assemblies as described in various notes/reports and publications released from this Section. This task took 10 years since research and development in processing codes and extensive intercomparison studies were involved with the use of a non-dedicated computer system.

TABLE 1

LIST OF ISOTOPES/ELEMENTS FOR WHICH DATA IS AVAILABLE IN KALPAKKAM MULTIGROUP SET (STATUS AS ON 1 AUGUST 1987).

NO	MATERIAL	BASIC FILE USED	NO	MATERIAL	BASIC FILE USED
1.	U-235	ENDF/B-IV	2	U-238	ENDF/B-IV
3.	PU-239	ENDF/B-IV	4	PU-240	ENDF/B-IV
5.	PU-241	ENDF/B-IV	6.	PU-242	ENDF/B-IV
7.	NI*	ENDF/B-IV	8.	CR*	ENDF/B-IV
9.	FE*	ENDF/B-IV	10.	NA*	ENDF/B-IV
11.	AL*	ENDF/B-IV	12.	SI*	ENDF/B-IV
13.	MN*	ENDF/B-IV	14.	MO*	ENDF/B-IV

TABLE 1 (CONTINUED)

LIST OF ISOTOPES/ELEMENTS FOR WHICH DATA IS AVAILABLE IN KALPAKKAM MULTIGROUP SET (STATUS AS ON 1 AUGUST 1987).

NO	MATERIAL	BASIC FILE USED	NO	MATERIAL	BASIC FILE USED
15.	C*	ENDF/B-IV	16.	N-14	ENDF/B-IV
17.	O*	ENDF/B-IV	18.	TH-232	ENDF/B-IV
19.	B-10	ENDF/B-IV	20.	B-NAT	ENDF/B-IV
21.	BE	ENDF/B-IV	22.	U-233	ENDF/B-IV
23.	U-234	ENDF/B-IV	24.	TH-232	JENDL-2
25.	U-233	JENDL-2	26.	TH-232	ENDF/B-V.2
27.	GA-NAT	ENDL-78	28.	U-236	ENDF/B-IV
29.	U-237$	ENDF/B-V ACTINIDE	30.	U-239$	ENDL-78
31.	NP-237$	ENDF/B-IV	32.	NP-238$	ENDF/B-V ACTINIDE
33.	NP-239$	JENDL-1	34.	PU-238$	ENDF/B-IV
35.	PU-243$	ENDF/B-V ACTINIDE	36.	AM-241$	ENDF/B-IV
37.	AM-242M$	ENDF/B-V ACTINIDE	38.	AM-242$	ENDF/B-IV
39.	AM-243$	ENDF/B-IV	40.	CM-242$	ENDF/B-V ACTINIDE
41.	CM-243$	ENDF/B-IV	42.	CM-244$	ENDF/B-IV
43.	ZR	ENDF/B-IV	44.	PA-231	ENDF/B-V ACTINIDE
45.	TH-231$	ENDL-84V	46.	TH-232	ENDF/V.2
47.	TH-232	ENDL-84V	48.	U-233	ENDL-84V
49.	U-234$	ENDL-84V	50.	U-235$	ENDL-84V
51.	U-236$	ENDL-84V	52.	U-237$	ENDL-84V
53.	U-238$	ENDL-84V	54.	U-239$	ENDL-84V
55.	U-240$	ENDL-84V	56.	NP-237$	ENDL-84V
57.	PU-238$	ENDL-84V	58.	PU-239$	ENDL-84V
59.	PU-240$	ENDL-84V	60.	PU-241$	ENDL-84V
61.	PU-242$	ENDL-84V	62.	PU-243$	ENDL-84V

* INCLUDES PART II FINE GROUP ELASTIC SCATTERING DATA

$ INFINITE DILUTION CROSS SECTION DATA ONLY

COMPUTER STORAGE AND ADAPTATION OF MULTIGROUP CROSS-SECTIONS

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Neutron multigroup cross-sections are the basic inputs to carry out the neutronics and safety studies of nuclear reactors. In order to study the criticality configurations of minor and major actinides from the considerations of nuclear safety and safeguards, 35 group cross-sections with P_3-anisotropic scattering matrices have been generated for several major and minor actinides using their basic cross-section data from ENDF/B-IV /1/, ENDL /2/ and JENDL-2 /3/ files.

The generated 35 group crosssections and P_3 -anisotropic scattering matrices have been converted to DTF-IV /4/ format and stored in computer files for Pa-231, Pa-233, U-233, Np-237, Am-241 and Cm-244 actinides. Criticality data for some of these elements have been obtained /5/ using these cross-sections.

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STATUS OF ACTIVITIES UNDER IAEA'S CO-ORDINATED RESEARCH PROGRAMME ON VALIDATION AND BENCHMARK TESTING OF ACTINIDES NCULEAR DATA

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This work was carried out at IGCAR, Kalpakkam within the scope of International Atomic Energy Agency Co-ordinated Research Programme on Validation and Benchmark Testing of Actinide Nuclear data (RESEARCH CONTRACT NO. 3690/R3/RB)

The programme of work agreed by IGCAR within the scope of this Research Contract (No.3690/R3/RB) is mainly directed towards improving and completing the Indian evaluated data files for Th-232 and U-233 in ENDF/B formats based on evaluations and integral validation studies and to make these data available to IAEA Member States.

The period of the research contract may extend upto June 1988. The details of the work done within the scope of this contract has been given under references (Ganesan, 1986;1987a;1987b).

The neutron interaction cross section data for INDIAN file for Th-232 in ENDF/B format was created on a magnetic tape as per following specification and the tape was transmitted to Dr. Lemmel, Project Officer for this research contract for suggestions and feedback.

1. Capture cross section for 50 keV to 20 MeV has been taken from Trombay evaluation.

2. The use of (Meadows, 1983) fission cross section upto 20 MeV from threshold.

3. The (n,2n) cross sections were accepted as in JENDL-2 file.

In order to have a complete file in ENDF/B format these partial data recommended by us were put in ENDF/B format by starting with JENDL-2 File.

The extensive comparisons of infinite dilution cross sections and self-shielding factors calculated by processing recent data files have been completed and results have been documented.

Analyses of JEZEBEL-23 an U-233 metal assembly has also been completed.

Theoretical calculations of neutron interaction cross sections for Th-232 and U-233 have been in progress. The optical statistical code ABAREX has been successfully commissioned and sensitivity calculations are being performed.

Further updating of the above mentioned Indian files is expected to be made as and when decisions are made.

Presently for the analyses of capture reaction rate in Th-232 in CFRMF assembly which has a flux spectrum covering 0.1 keV to 1 MeV region, the flux spectra given in BNL specification has been follwed. The following data files have been identified for intercomparison:

1. ENDF/B-V received from BNL and processed in 1986. The task of processing this file has been completed.
2. JENDL-2 file.The task of processing this file has been completed.
3. INDIA file.

Further critical evaluation and compilation of benchmarks for data testing purposes for Th-232 and U-233 and examination of differential cross sections are being continued.

Based on several considerations it has been tentatively decided to take for the Indian file the inelastic cross sections for discrete levels and their angular distributions as provided by Sheldon's theoretical evaluations and use the file for some integral tests. A firm conclusion can be arrived at thereafter. The technical work of coding this data in ENDF/B format is in progress: This task includes some consistensy checks as well.

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GANESAN S. (1987b) "Neutron Cross Sections for U-233: (a) Processing and Intercomparison of JENDL-2, ENDF/B-IV and ENDL-84 Basic Evaluated Data Files (b) Integral Validation Study in the Fission Source Energy Range by Analyses of U-233 Spherical JEZEBEL Assembly (c) The Analyses of U-233 Irradiation Experiment in RAPSODIE Experimental Fast Reactor", Report for submmital to International Atomic Energy Agency Co-ordinated Research Programme on Validation and Benchmark Testing of Actinide Nuclear Data (Research Contract No.3690/R3/RB) Release Date: August, 1987.

MEADOWS J. W. (1983) ANL/NDM-83. Argonne National Laboratory.

PREDICTION OF MASSES OF ATOMIC NUCLEI IN THE INFINITE NUCLEAR MATTER MODEL

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The masses of 3481 nuclei in the range $18 \lesssim A \lesssim 267$ have been predicted through a new mass formula developed over the last several years. This mass has many-body theoretic foundation. Sometimes back, we had obtained[1] a mass relation for nuclei starting with the Hugenholtz-Van-Hove [HVH] theorem in the many-body theory. Its success was demonstrated in predicting masses of exotic neutron rich nuclei far from stability. Although its success is very impressive it does not have very satisfactory extrapolation property when used as a recurrence relation. Recently one of us proposed a model called infinite nuclear matter [INM] model[2] which extends this mass relation into a mass formula with reliable predictive power.

The INM model recognises that the nuclei in general possesses two categories of properties namely the universal and the individualistic. In this model, the ground-state energy of an atomic nucleus with asymmetry parameter β is considered equivalent to the energy of a perfect sphere made up of infinite nuclear matter of the same asymmetry β plus the residual energy η called the local energy. η represents the energy due to shell, deformation and diffuseness etc and thus individualistic in nature. Using this picture and the generalized HVH theorem the previously proposed mass relation is derived in a transparent way in which η drops away in a very natural manner. A recurrence relation for η is derived which has excellent extrapolation property. This property of η in conjugation with the universal property of the INM sphere defines the mass formula. Thus in this model there are two kinds of parameters: Global and local. The five global parameters are determined once for all by fitting the masses of all nuclei (756) in the recent Audi and Wapstra mass table with error bar less than 30 keV. The local parameters are determined for 25 regions defined by A = 8 or 10 . The total number of parameters including the five global ones is 238. The root mean square deviation for the calculated mass from the experiment is 397 keV for 1572 nuclei used in the least square fit. The details of the mass table containing predictions for 3481 nuclei will appear elsewhere[3].

As a measure of the success of this mass formula we present in Table 1 a comparision of our predictions on Na isotopes with those of the recent predictions of Kelson group[4] and of Janecke group[5]. As is well known the prediction of the masses of Na isotope pose a serious challenge to most of the mass formulae. However it can be seen from Table 1, that our prediction agree quite well with the experiment.

Table 1 : Comparision of mass excess in MeV Error given in parenthesis

Isotopes	Expt.	Present work	Comay Kelson & Zidon	Janecke and Masson
Na^{28}	-1.14 (0.14)	-0.91 (0.54)	-1.05 (0.42)	-0.87
Na^{29}	2.65 (0.15)	2.95 (0.28)	2.26 (0.64)	2.12
Na^{30}	8.21(0.25)	7.6(0.22)	8.81(0.80)	8.36
Na^{31}	11.83(0.58)	10.93(0.22)	13.58(1.07)	12.74
Na^{32}	16.55(0.74)	18.58(0.26)	22.42(1.2)	21.37
Na^{33}	21.47(1.14)	21.87(0.32)	28.62(1.41)	27.69
Na^{34}	26.65(3.57)	25.99(0.51)	37.24(1.55)	36.48
Na^{35}		29.28(0.73)		

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^{89}Y+n RESONANCES : PARITY DEPENDENCE OF LEVEL DENSITY

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Measurement of the neutron total cross sections of nuclei provide useful information about the resonance parameters and average nuclear properties such as level density, strength function, etc. High resolution neutron total cross section of ^{89}Y has been measured from about 10 to 750 kev using the pulsed neutron time of flight spectroscopy at ORELA with a neutron burst width of 5 ns and a nominal resolution of 0.025 ns/m at the highest energy. The choice of 89Y for these measurements was made to test the parity dependence of level density and the presence of intermediate structure. Preliminary results with the emphasis on IS have been presented in APS meeting/1/. The present paper deals with the level density.

An R-matrix MULTI code/2/ was used to fit the shape of the measured cross section and the precise values of the resonance parameters (E_0 ,$g\Gamma_n$,J^π) have been determined. Fig.1 shows a typical sample of theoretical fits to the experimental data.

The slopes of straight lines drawn through the plots of the cumulative number of $J^\pi=0^-$ and 1^- s- wave resonances; $J^\pi=0^+$, 1^+, 2^+ p-wave resonances vs. neutron energy yielded average level spacing $\langle D\rangle(\ell=0)=(4.6 \pm 0.3)$ keV and $\langle D\rangle(\ell=1)=(1.34 \pm 0.15)$ keV upto 600 keV. Thus the experimental value of $D_0/D_1 = (3.43 \pm 0.6)$. From the level density formula which predicts a J dependence (for either parity) of the form $(2J + 1)\ \exp- (J+\frac{1}{2})^2/2\sigma^2$, one would obtain a value of $D_0/D_1 = 2.06$ (for $\sigma=3.8$). This value is much smaller than the experimental value of 3.43, indicating of a parity dependence of the level density of ^{89}Y at high excitation following our recent conclusion /3/ of parity dependence of the level densities of ^{53}Cr and ^{55}Cr at high excitation. In past, for many nuclei the assumption of parity independence of level density was found to be in Jeopardy (e.g. reference 6, 18-23 of our paper /3/). Soloviev et.al./4/ calculations do indicate that the ratio of the number of positive parity states to the number of negative parity states is not one at the neutron B.E. for many nuclei.

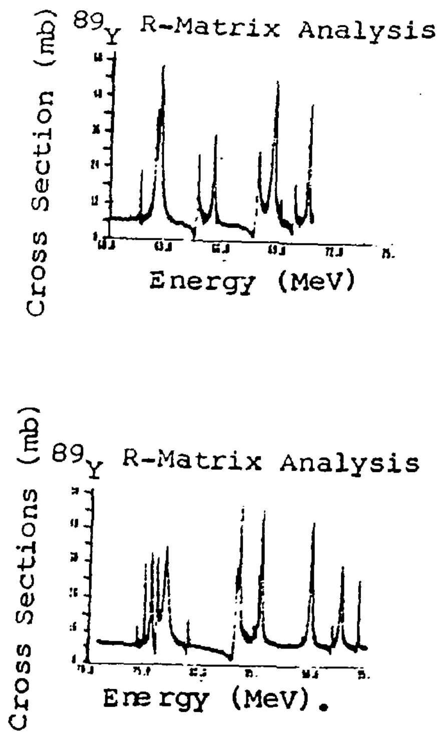

FIG. 1

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+Helpful discussions with J.B.Garg (SUNY Albany) and J.A. Harvey (ORNL) are gratefully acknowledged.

NUCLEAR LEVEL DENSITY PARAMETER OF HIGH SPIN NUCLEI

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In the present work, the effect of spin on nuclear level density parameter/1/ has been investigated. The shell correction as a function of angular momentum is calculated by extending the thermodynamical method of V.S.Ramamurthy et al., /2/ to rotating nuclei. Here we use the single particle levels corresponding to the rotating nuclei (Cranked Oscillator Level /3/) in the statistical formalism.

In this formalism, the angular momentum is directly obtained from the sum of the single particle angular momentum with corresponding occupation probabilities which are now different, since the degeneracy with respect to the projection quantum number Ω is removed.

The single particle level density parameter **a** (M,T) as a function of spin and temperature is given by

$$a(M,T) = S^2(M,T)/4E^*(M,T) \text{ - - - - - } (1)$$

where S is the entropy and E^* is the excitation energy.

$$E^*(M,T) = E(M,T) - E_0 \text{ - - - - - - - - - - } (2)$$

where E(M,T) and E_o are the total energy and the ground state energy of the nucleus respectively.

The shell correction is calculated for a particular deformation, as a function of spin using the relation.

$$S^2 = 4a\left(E^*(M,T) \pm \Delta E_{shell}\right) \text{ - - - - - - } (3)$$

where Δ Eshell is the shell correction.

Fig.1. shows the single particle level density parameter as a function of spin and temperature for the nuclei $_{66}Dy^{158}$. At low temperatures, the effect of rotation in the single particle level density parameter is very much pronounced and the shell structure is predominant.

Fig.2. depicts the shell correction as a function of spin, which show fluctuations giving rise to minima for large angular momentum states. The minima may have some connection with the back-bending found in the nucleus at large angular momentum

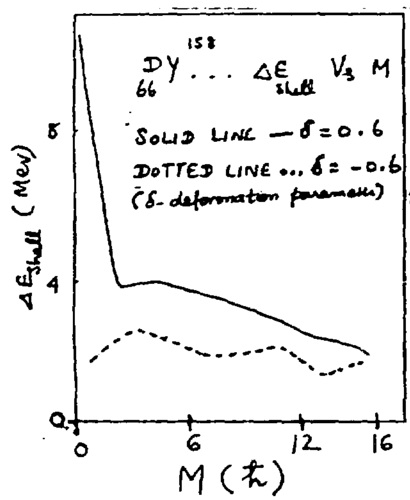

FIG. 2

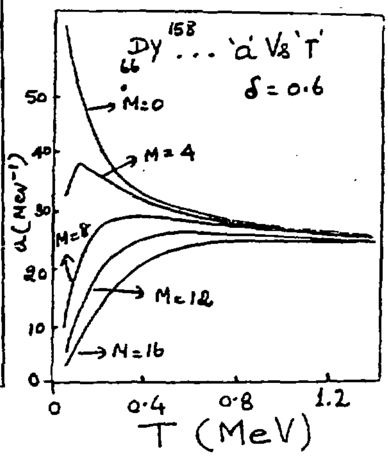

FIG. 1

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RADIOACTIVE DECAY OF NB-91M

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The latest information on the decay of NB-91m as furnished in Nuclear Data Sheets indicates that the experimental value of the total conversion coefficient of the 104.5 keV ($1/2^{+}-9/2^{-}$) transition to be approximately 50 in violent disagrement with the value[3] of 171.1 expected for an M4 transition. From the systematics of low energy states of odd-mass nuclei in this region, the spin assignments appear to be in order. Therefore, in the present work, the K-conversion coefficient of this transition is accurately measured for the first time.

EXPERIMENTAL: The reaction Y-89 (alpha,2n) NB-91m, at the alpha beam energy 20 MeV, was used to produce the 62-day isomer at the V.E.C. Centre, Calcutta. Two targets of natural Y_2O_3 (made by suspension in liquid paraffin and centrifuging to stick onto a 3mg/cm^2 aluminised mylar foil), each of thickness 10mg/cm^2, were used in the experimental runs. The half-life of NB-91m being 62 days, the spectra were recorded using a 15% Ge(Li) (FWHM 2.1 keV at 1332keV), 10% and 30% HPGe detectors (FWHM 165 eV at 5.9keV) and analysed (using the Canberra 80 and 88 analyser systems) to identify the gamma rays belonging to NB-91m as well as other activities produced (Y-90m and NB-92m) based on their respective half-lives.

The decay scheme based on the identified X-ray and gamma ray transitions is shown in Figure. The relative intensities of the K X-rays, 104.5 keV and 1204.7 keV gamma rays were determined from the HPGe spectra. The K X-ray peak in this case, however, includes contributions from the NB and the ZR K X-rays arising respectively from internal conversion and electron capture. The relative intensities of the ZR and NB K X-rays were determined from the spectra recorded with the Si(Li) detector and this was used to estimate the NB fraction from the composite K X-ray line recorded with the HPGe detector.

RESULTS AND DISCUSSION: The relative intensities of the extracted K X-ray and the 104.5 keV transition were employed to determine the K conversion coefficients of the 104.5 keV transition. An average of six experimental runs yielded a value of α_K to be 114.5 (42) which is in disagreement with the earlier experimental values. The present value agrees quite well with that expected for a pure M4 transition (Hager and Seltzer[3]: 117.1 and

Rosel[4] et al : 118.2). From the present values of α_K (104.5) and the relative intensities and the previous conversion data, the isomeric and electron capture decay fractions are extracted to be 97.6% and 2.4% respectively. Assuming that all electron capture leads to the formation of the 1204.7 keV state, the ratio of the 104.5 keV gamma ray intensity to the total intensity of electron capture is obtained as 0.244 (6). On the other hand, the same ratio, deduced from the ZR and NB K X-ray relative intensities, yielded a value of 0.111 (3). This discrepancy may either be a result of an unusually large L capture or a possible ground state feeding of electron capture.

The gamma ray transition probability of the 104.5 keV gamma ray is determined from the present α_K value and relative intensities together with the earlier K/LM data. This shows an enhancement by a factor of about 2 over the Weisskopf estimate indicating a nearly pure single particle excitation, consistent with the trends observed in this region of nuclei.

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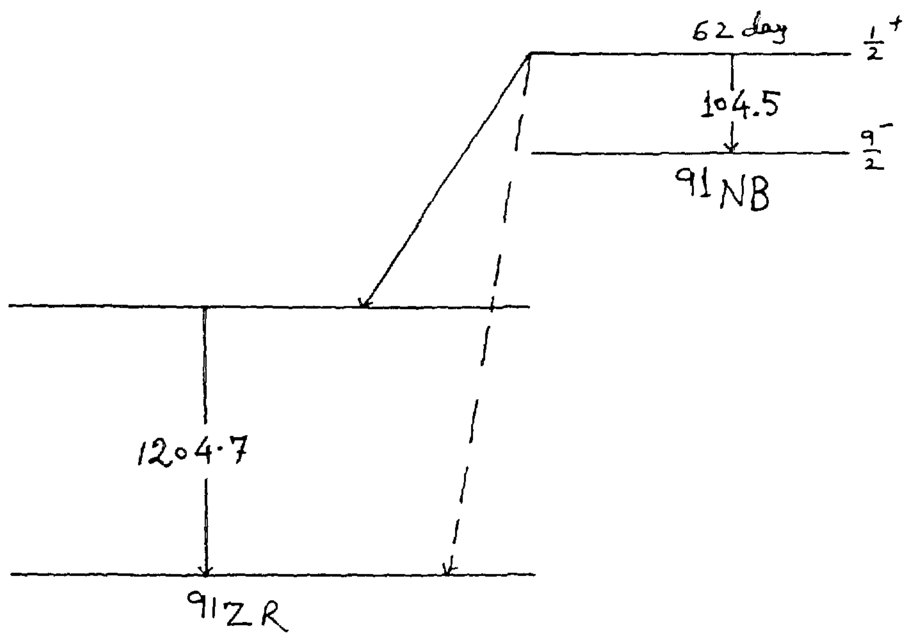

DECAY SCHEME OF ^{91m}NB.

STUDY OF Ir-192 DECAY

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The low lying levels of Pt-192 and Os-192 populated in the β and EC decay of Ir-192 have been studied. The relative gamma-ray intensities of 28 gamma-rays have been precisely measured using a well calibrated 64.1 c.c. HPGe detector (FWHM=1.7kev at 1.332 Mev). The present gamma-ray intensities are in general agreement with the previous reported values (1). However, the present intensity values for weak cross-over gamma transitions at 624-, 784-, and 921-kev are found to be considerably lower than the earlier measurements (1). This difference may be attributed to large necessary summing corrections for these gamma-rays. It may be mentioned that intensity of 1201-kev gamma ray is found to be almost zero, within the experimental errors after applying summing corrections.

Table 1: Relative intensities of gamma-rays in Ir-192 decay

Energy (kev)	Present	Eid et al (1)	Energy (Kev)	Present	Eid etal (1)
110.0(Os)	0.016(1)	0.011(4)	489.0(Os)	0.547(5)	0.49(5)
136.3(Pt)	0.307(10)	0.209(8)	588.6(Pt)	5.56(5)	5.47(9)
201.3(Os)	0.578(10)	0.62(2)	593.4(Pt)	0.052(2)	0.0043(7)
205.8(Os)	4.22(3)	3.93(7)	604.4(Pt)	10.10(9)	10.39(18)
283.2(Os)	0.321(5)	0.317(9)	612.4(Pt)	6.61(6)	6.77(12)
296.0(Pt)	34.94(18)	34.81(66)	624.9(Pt)	0.030(2)	0.037(2)
308.5(Pt)	35.81(20)	36.34(73)	703.6(Os)	0.0069(5)	0.006(2)
316.5(Pt)	100.0(5)	100	784.2(Pt)	0.031(2)	0.023(2)
328.9(Os)	0.019(2)	0.023(1)	885.5(Pt)	0.360(3)	0.366(6)
374.5(Os)	0.889(7)	0.87(2)	904.5(Os)	0.0044(5)	0.0034(10)
416.4(Pt)	0.834(8)	0.77(2)	920.8(Pt)	0.0027(7)	0.0095(9)
420.6(Os)	0.092(3)	0.078(4)	1061.5(Pt)	0.067(2)	0.063(2)
468.1(Pt)	58.01(41)	58.24(97)	1090.3(Pt)	0.0012(2)	0.0018(5)
484.6(Os)	3.92(3)	3.62(7)	1200.7(Pt)	0.0002(3)	0.0022(1)

Gamma-gamma directional correlation measurements have been done for 9 cascades in Pt-192 and 4 cascades in Os-192 using a 96 c.c. HPGe-90 c.c. HPGe detector set-up (energy resolution 1.7 kev at 1.332 Mev; time resolution ~ 7ns for Co-60 gamma cascade). The directional correlation coefficients from the present work have been further used to deduce the mixing ratios for 201-, 283-, 485-kev transitions in OS-192 and 296-, 308-, 416-, 604-kev transitions in Pt-192 by the method described by Krane and

Steffen(2). The 206- and 489-kev gamma transitions in Os-192 and 316-, 468-, 589- and 612-kev gamma transitions in Pt-192 were assumed to be pure E2 on the basis of ICC measurements(3).

Table 2. Directional correlation measurements results

Cascade	Spin (+)	Correlation coefficient A22	A44	Mixing ratio (δ)
Pt-192				
296----316	220	-.172±.004	.339±.005	$\delta(296)=7.1\pm0.3$
589----296	422	-.[illegible]5±.016	-.025±.026	
$308\overset{296}{\frown}316$	3(22)0	.016±.004	-.022±.006	
612----308	320	-.105±.024	-.053±.035	$\delta(308)=6.9\pm0.5$
309----296	322	-.011±.006	-.025±.008	
$589\overset{296}{\frown}316$	4(22)0	-.020±.031	-.068±.045	
468----316	420	.106±.003	-.001±.005	
$416\overset{468}{\frown}316$	4(42)0	-.222±.041	.112±.070	$\delta(416)=2.9\pm1.0$
604----316	320	-.536±.004	-.014±.005	$\delta(604)=-1.2\pm0.1$
Os-192				
374----206	420	.098±.033	.059±.049	
283----206	220	.234±.102	.164±.150	$\delta(283)=-2.3^{+0.7}_{-1.3}$
485----206	320	-.318±.006	-.075±.009	$\delta(485)=-6.5\pm0.4$
489----201	320	-.377±.057	.032±.076	$\delta(201)=-4.1^{+1.2}_{-2.3}$

The spin value of 2^+ assigned to 1201 kev level by Eid et al (1) has been ruled out and a 4^+ spin to this level is reaffirmed on the basis of (i) absence of 1201-kev gamma transition to ground state (4^+--0^+) (ii) $416\overset{468}{-}316$ kev directional correlation results, which give imaginary values of δ for $2^+(4^+2^+)0^+$ spin sequence.

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DECAY OF 3S ISOMER OF ^{160}HO

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1. Introduction. Several low lying isomeric states are known to exist in ^{160}Ho below 500 KeV. However, except for the 5 hr. isomeric state, the assignments and decay schemes for the rest are uncertain (1,2). The present work is aimed at establishing the lowlying isomeric states in ^{160}Ho.

2. Experimental. ^{160}Ho was produced by (α,3n) reaction on Tb (1mil). Four different energies : E_{α}=29,35,41 & 45 MeV were used in order to study the excitation function. For the study of short-lived isomers the recoil products were transported to a distance of about 35 ft. using Gas Jet Recoil Transport technique. The activities were collected on thin Al foils and were counted insitu using a 30% HpGe and a LEPS detector. The data were recorded in the SMS mode on a Canberra series-88 MCA. In a single cycle of data acquisition the target was bombarded for 4 secs and after a cooling time of 1 sec, eight 2K spectra each of 2 secs dwell time were recorded in the singles mode. The same cycle is repeated several times for adequate statistics. For longer lived isomers the activities were collected for about ½ hr. and the decay was then followed.

3. Results and discussions : Fig.1 shows the decay curves for γ-rays belonging to the 3 secs ^{160}Ho isomer. Besides, the 51,107 and 118 KeV γ-rays the K-Xray of Ho was also found to decay with a 3 sec. component confirming the Z assignment. The isotopic assignment has been done on the basis of γ-ray excitation function data. Based on observed γ-ray energies, intensities and deduced multipolarities a decay scheme for the 3 sec. isomer is proposed (fig.1). This scheme is in conformity with the low lying level structure of ^{160}Ho and other neighbouring odd-odd Ho isotopes, as observed in recent in beam γ-ray measurements. The 11 KeV transition placed between 118.4 KeV and 107.3 KeV states could not be observed in our case as expected from internal conversion considerations. We did not also observe any direct transition from the isomer feeding any of low lying states. The position of the isomer is, therefore,

uncertain. However, an upper limit of 225 KeV is set from K X-ray intensity balance. As regards (9^+) 1 hr. isomer reported earlier, our data do not confirm the existence of such an isomer in ^{160}Ho.

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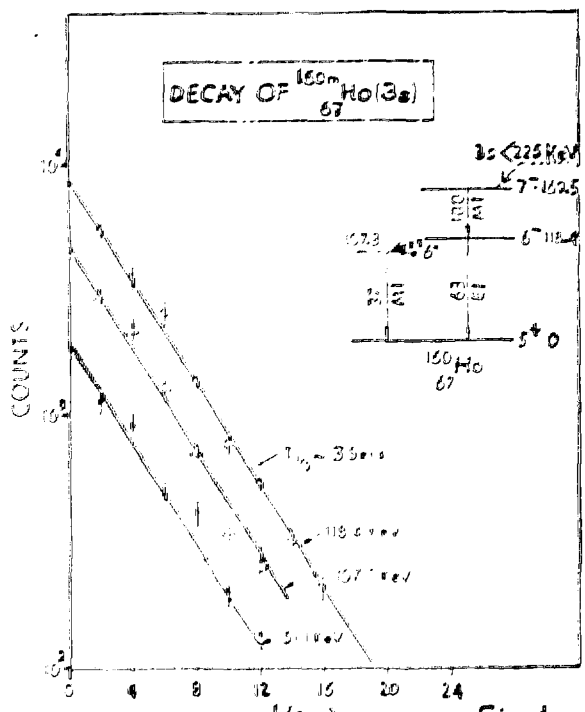

Fig-1

ENTRANCE CHANNEL EFFECTS ON FISSION FRAGMENT ANISOTROPIES – A DIRECT EXPERIMENTAL SIGNATURE OF FISSION BEFORE EQUILIBRATION (PRE-EQUILIBRIUM FISSION)

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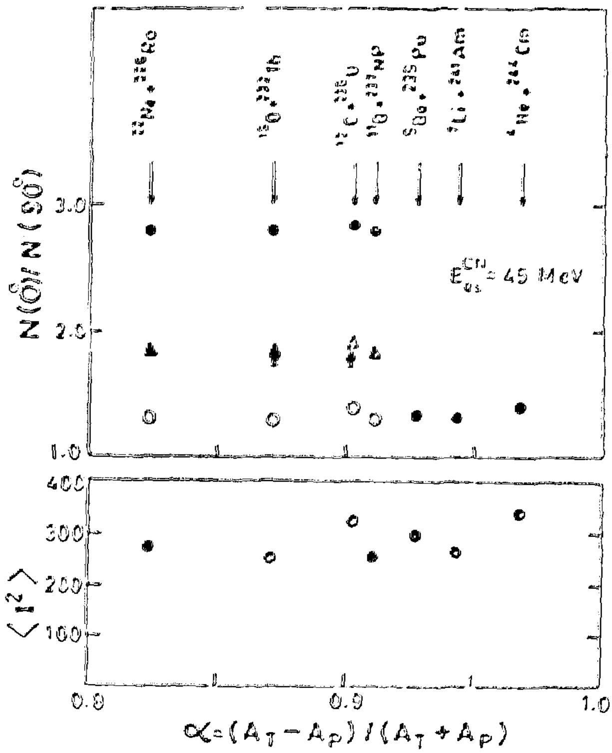
In a number of recent investigations of heavy ion induced fission reactions, apparently anomalous angular distributions have been measured. We have recently shown that these arise due to a fraction of the fission events taking place before the formation of the fully equilibrated compound nucleus if the composite system has a fission barrier height comparable to its temperature. A memory of the entrance channel reaction plane is exhibited in these pre-equilibrium fission events and from the analysis of the data a value of 8×10^{-21} s was deduced as the K equilibration time resulting in abundant pre-equilibrium fission events and considerable reduction in the compound nucleus formation cross section from its standard value. Given the significance of these conclusions on the dynamics of heavy ion fusion reactions and the subsequent formation of a compound nucleus, an independent means of verifying the validity of the proposed mechanism is of considerable interest. For this purpose we have studied the entrance channel dependence of the fission fragment anisotropies. The compound nucleus chosen for the present investigations is 248Cf at an excitation energy of 45 MeV. The cross section for fusion and the partial wave distributions for the different entrance channels are calculated on the basis of the one dimensional fusion barrier model with tunneling. For a calculation of the fragment anisotropy including pre-equilibrium fission, two additional considerations are relevant: i. the range of entrance channel mass-asymmetry includes the Businaro-Gallone ridge. It is known that when the mass asymmetry is more than the Businaro-Gallone ridge, the potential energy versus mass asymmetry is such that the system is driven towards further mass asymmetry and no mass symmetric fission-like events can result if the composite system splits before the formation of the compound nucleus; this implies that no pre-equilibrium fission events will result in this case.
ii. the K equilibration time as deduced in our earlier investigation refers to angular momentum values in the range of 30 to 40. However, in the present investigations, much smaller values of angular momenta are invlolved. Therefore a somewhat different equilibration time can be expected.

With these comments in mind, we have shown in figure 1 the calculated anisotropies as a function of the entrance channel mass asymmetry for two values of the K equilibration time, 8×10^{-21} s and 2×10^{-21} s. A step like change in the anisotropy at the Businaro-Gallone ridge is clearly seen though the magnitude of the step depends on the assumed value of the K equilibration time.

A measurement of the fission fragment anisotropies for the systems under investigations here will therefore provide unambiguous experimental support for the occurence of pre-equilibrium fission. While such a complete data does not exist at present, figure 1 also shows three existing measurements with He, C and O projectiles, though not at the exact bombarding energies required. Although evidence for the existence of a step like behaviour is already indicated, there is a need for more measurements for the different systems suggested here.



50 MEV ALPHA PARTICLE INDUCED NEUTRON PRODUCTION REACTION ON BE

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Introduction: In this paper we describe an experiment in which the neutron production cross-section through(α, Xn) reaction induced by 50 MeV alpha particle on Be is measured. We have chosen Be as target because there are very few studies in which neutron emission is observed by bombarding Be with alpha.

From the energy spectra of emitted neutrons we are intended to study the direct connection of it with reaction mechanism.

With this view in mind we have set-up our experiment utilising the alpha beam provided by the Variable Energy Cyclotron at Calcutta.

Experiment: The alpha particle induced reaction where neutron production cross-section is considered, γ-ray photons are also emitted in such reactions. For detecting neutrons in presence of γ-rays we used conventional liquid scintillation pulse shape discrimination technique to separate neutrons from γ-ray photons.

We have used Be target of 3 mm thickness which can totally absorb the 50 MeV incident α-particles. Beam current used was 10-20 mA. Energy spectra of neutrons at three emission angles 0°, 30° and 60° were recorded.

Result and Analysis: General tendencies shown by the emitted neutron spectra is that with larger emission angle the spectra becomes softer.

Following Chiang and Hufner [1] we try to analyse our data by casting the double differential corss-section in the form

$$\frac{d\sigma}{d\Omega . dE} = \sum_{i} \frac{d\sigma^{(i)}}{d\Omega . dE} + \frac{d\sigma^{(c)}}{d\Omega . dE}$$

where the index i corresponds to single, double etc. scattering and the index C represents the compound nucleus formation and decay. Each term of the above eqn. is factorized into three contributions

$$\frac{d\sigma^{\nu}}{d\Omega\, dE} = N_{\nu}.\sigma_{\nu}(E_0).\, F_{\nu}\,(\Omega\,, E\,, E_0)$$

where ν =1,2.....,C. This factorization is an assumption and for energies below 100 MeV its validity needs to be tested by comparison with experiment. The numbers N_{ν} give the number of nucleons after single, double or compound decay. The dependence of the corss-section on the angle and the final energy E is contained in the functions F which are normalized according to

$$\int d\Omega\, dE\, F_{\nu}(\Omega\,, E\,; E_0) = 1$$

σ_{ν} are the cross-sections forsingle, double and compound nucleus formation respectively. This cross section in which a particle m_1 with momentum P_1 enters a nucleus and strikes a particle m_2 with a given momentum distribution thus producing a final particle m_f with momentum between P_f' and $P_f' + dP_f'$ is given by Kikuchi and Kawai [2] as

$$\frac{d\sigma_i}{dp_f'}(p_f')\,dp_f' = \frac{m_1}{p_1}\int v_{rel}\,\frac{dn(p_2)}{dp_2}\;\frac{d\sigma_{CM}(K_1,K_f')}{dK_f}\;dK_f'\,dp_2$$

The momentum distribution is taken as

Ferrero et al[3] have deduced

the fre nucleon cross section in the CM system of two colliding particles where K's are their momenta. We have used their expression for our alpha induced neutron emission reaction. Uptill now we have considered only single scattering and the results thus obtained will be reported in the symposium.

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