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Total Neutron Yields from 100 MeV Protons on Pb and ^{7}Li Targets

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This work has been published in Nuclear Instruments and Methods, 214, 333-339 (1983) with the following abstract:

"The neutron yield per proton from thick targets of Pb and ^{7}Li irradiated with 100 MeV protons has been measured and calculated. The water bath method was used to measure the neutron production and a Faraday cup was used to measure the proton beam current. Measured yields are 0.343±0.021 for Pb and 0.123±0.007 for ^{7}Li. Corresponding yields calculated with the nucleon-meson transport code NMTC are 0.363±0.002 and 0.160±0.001. Measured and calculated thermal neutron distributions in the water bath are also compared."

Total Neutron Yields from 100 MeV Protons on Cu, Fe and Th Targets

M.A. Lone, R.T. Jones, A. Okazaki and B.M. Townes (CRNL); J.K.P. Lee, R.B. Moore and L. Nikkinen (McGill University)

Measurements of total neutron yields from (p,xn) reactions at 100 MeV, on thick Cu, Fe and Th targets, were made using the proton beam of the McGill University cyclotron. The neutrons produced were thermalized in a tank of light water and the resulting thermal neutron flux distributions were measured with gold foils. The results, given in Table 1, have been corrected for capture of fast neutrons and for leakage, using values from NMTC/MORSE calculation of the yields. The calculated yields are also given.

Table 1. Measured and calculated neutron yields from (p,xn) reactions at 100 MeV.

Target	Measured Yield (neutrons/proton)	Calculated Yield (neutrons/protons)
Iron	0.12	0.118 ± 0.003
Copper	0.15	0.162 ± 0.004
Thorium	0.54	0.448 ± 0.008

Agreement is satisfactory for the iron and copper targets when judged against the estimated experimental uncertainty of ±6%. The measured yield for thorium is, however, some 20% higher than that calculated. This is believed to be due to the NMTC calculations not including a fission channel in the decay modes available to excited nuclei.

Characteristics of a Thermal Neutron Source Based on an Intermediate Energy Proton Accelerator

M.A. Lone, W.N. Selander, B.M. Townes, J. Latouf, E.C. Svensson and G.A. Bartholomew

This work has been published as report AECL-7839, with the following abstract:

"The envisaged development program leading to a 1 GeV, 300 MW accelerator breeder pilot plant would require construction of three high-current proton test accelerators of progressively increasing energy. These accelerators would also be available to drive neutron sources for other applications. This report explores the characteristics of the high-intensity thermal neutron source that would be provided as part of the Electronuclear Materials Test Facility (EMTF), which is envisaged as a multi-purpose test system based on the accelerator of intermediate energy. Two options, a 300 mA cw proton beam at 100 MeV and a 70 mA cw proton beam at 200 MeV are considered. It is shown that the 70 mA, 200 MeV accelerator with a Pb-Bi eutectic target would provide an unperturbed peak thermal neutron flux of $\sim 1.5 \times 10^{15}$ $n.cm^{-2}.s^{-1}$ in a relatively large volume of a D_2O moderator. The 300 mA, 100 MeV accelerator with a ^7Li target and graphite moderator, would provide a peak thermal neutron flux of $\sim 6.0 \times 10^{14}$ $n.cm^{-2}.s^{-1}$. Thermal neutron fluxes in various other moderators and heat limitations in various target configurations are also investigated.

Measurement of Effective Cross Sections for Low Temperature Thermal Neutrons

R.T. Jones, G.A. Doncaster and A. Okazaki

Several fission and capture cross sections for low temperature neutrons have been measured in a liquid-nitrogen cooled cryostat in the ZED-2 reactor. These measurements, described in NEANDC(Can)-52/L, are similar to those made previously in hot-moderator samples and described in AECL 6483 (Dependence of Effective Cross Sections on Thermal Neutron Temperatures, by R.T. Jones and A. Okazaki, 1979). Measurements have now been made at -197°C, -110°C, -77°C and 23°C for ^{233}U, ^{235}U and ^{239}Pu fission and for ^{238}U, ^{232}Th, ^{115}In, ^{176}Lu and ^{197}Au capture.

The results are relevant to discrepancies pointed out at the IAEA Consultants' Meeting on Uranium and Plutonium Isotope Resonance Parameters, Vienna, 1981 (INDC(NDS)-129/GJ), where a 2% difference was noted between the measured thermal Maxwellian-averaged cross section of ^{235}U and that obtained from the recommended 2200 $m.s^{-1}$ cross section and the Wescott g-factor. Problems with the shape (g-factor) of the ^{238}U neutron capture cross section were also indicated.

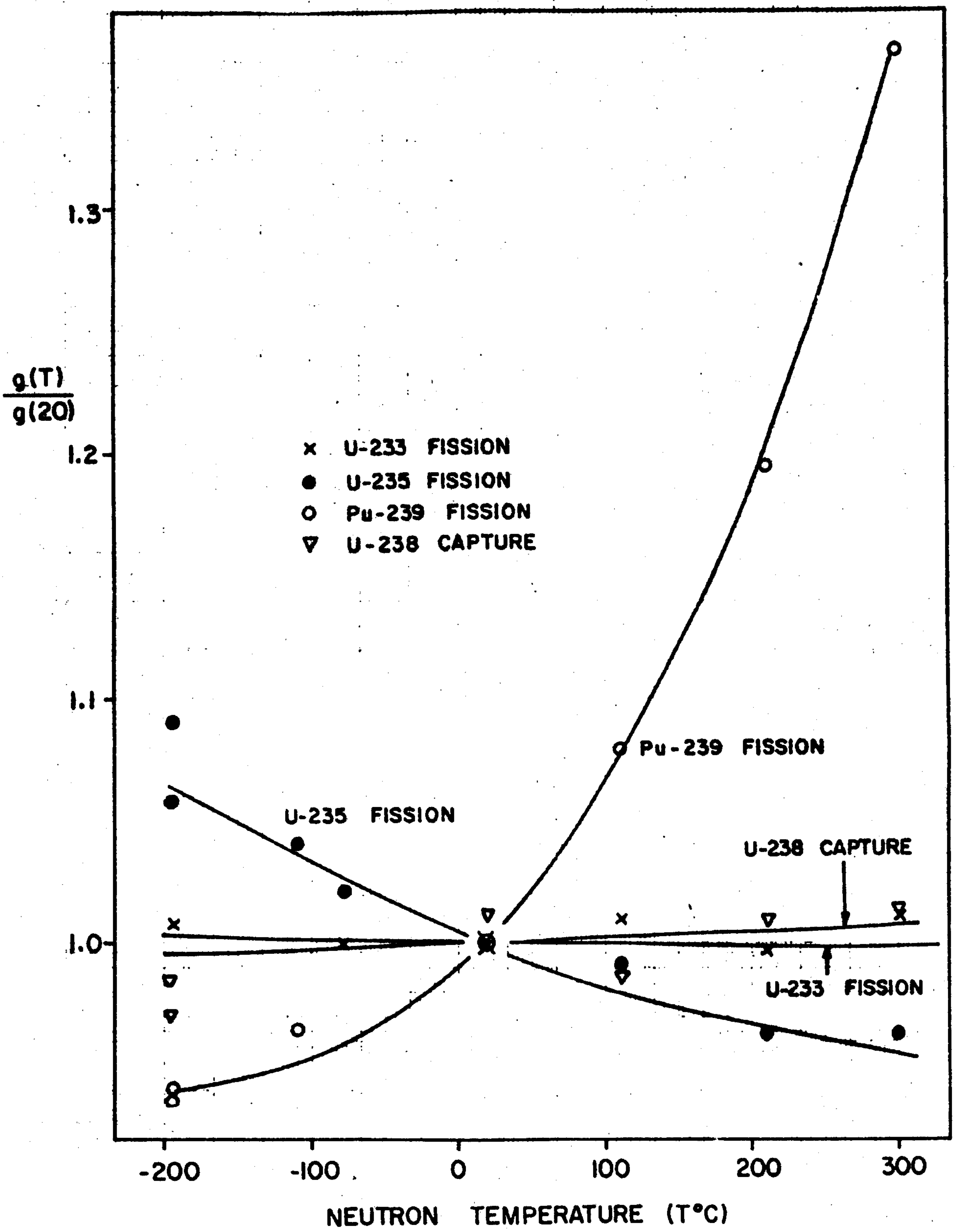

Figure 1. Ratio of Effective Cross Sections vs Neutron Temperature.

Some of our results are shown in Figure 1, together with those derived from ENDF/B-V by M. Milgram (curves). The ratios of effective cross sections at neutron temperatures T and 20°C (g(T)/g(20)) are plotted as a function of T. Our results indicate that the ENDF/B-V data describe the shapes of the ^{233}U, ^{235}U and ^{239}Pu fission and ^{238}U capture cross sections satisfactorily. The discrepancy in the ^{235}U fission cross section does not appear to be due to its shape.

The Prompt Response of Bismuth Germanate and NaI(Tl) Scintillation Detectors to Fast Neutrons

O. Häusser, M.A. Lone, T.K. Alexander and S.A. Kushneriuk (CRNL); and J. Gascon (Université de Montréal)

The work has been published in Nuclear Instruments and Methods, 213, 301-309 (1983) with the following abstract:

"Spectral distributions and yields of scintillation pulses from the prompt interaction of neutrons with 7.6 cm diameter x 7.6 cm long bismuth germanate (BGO) and NaI(Tl) detectors have been measured. Neutrons at energies between 0.4 and 10 MeV were produced by the $^{7}Li(p,n)$ and the $^{197}Au(p,n)$ reactions, respectively, and identified by their time-of-flight relative to the pulsed proton beam. For both scintillators the neutron response is dominated by $(n,n'\gamma)$ reactions, and the efficiences are in qualitative agreement with simple estimates that depend on the non-elastic and elastic cross sections, and on two geometrical factors. Compared to NaI(Tl), BGO exhibits a much superior gamma-ray-to-neutron detection ratio".

A Proposal to Measure the Effective Neutron Capture Cross Section of ^{147}Nd

L.W. Green, R.T. Jones and M.S. Milgram

Reports in the literature and results from our experiments indicate that the effective neutron capture cross section of ^{147}Nd is much larger than previously estimated; however, because of experimental difficulties, a precise measurement of the cross section has not been achieved. There is widespread interest in this cross section, because the higher value implies a significant bias in burnup values determined by the ^{148}Nd method. This proposal describes a method whereby the cross section is determined from the quantity of ^{148}Nd produced by irradiation of ^{146}Nd in a reactor; thermal ionization mass spectrometry will be used to measure the Nd isotopes and the flux/time history will be used to account for decay of ^{147}Nd. The method should provide a more precise value than previous methods.

A Preliminary Interpretation of the Fine-Structure Observed in the Photofission of ^{238}U

J.W. Knowles and W.F. Mills

We have estimated fission transmission factors T_f for ^{238}U from the photofission cross sections measured between 4950 and 6350 keV. For these estimates we required photo-absorption cross sections σ_a, γ-ray transmission factors T_γ and neutron transmission factors T_n above the neutron separation energy of ^{238}U at 6.147 MeV. Values of σ_a were obtained from the extrapolated tail of the giant dipole resonance cross section (A. Veyssiere et al., Nucl. Phys. A199 (1973) 45) and values of T_γ were calculated using σ_a and level density distributions for electric dipole γ-ray transitions in ^{238}U estimated by Gilbert and Cameron (Can. J. Phys. 43 (1965) 1446). Values of T_n for ^{238}U were determined as described by Khan et al. (Nucl. Phys. A179 (1972) 333).

We have evidence for a completely open fission channel in ^{238}U at 6.4 MeV where T_f is equal to unity. Previous measurements of the angular distribution of fission particles following (γ,f) in ^{238}U (Knowles et al. Izv. Akad. Nauk. Ser. Fiz. 34 (1970) 1627) show that, of the three possible channels, $J = 1^-$, $K = 0$ and 1, and $J = 2^+$, $K = 0$, only fission via the first channel is prominent in the energy range 5.5 to 6.4 MeV. Assuming that this fission channel is described by a double-humped fission barrier, our measurements are consistent with inner and outer barriers of 5880 and 6400 keV respectively, in reasonable agreement with those obtained by Back et al (Phys. Rev. C9 (1974) 1924). However, a simple double-humped fission barrier cannot account for the fine-structure observed in the T_f spectrum. This spectrum shows sharp increases in slope at 5510, 5880, 6150 keV which would correspond to equally sharp decreases in slope, indicating shelves at these energies, in the outer or inner surfaces of the potential energy distribution describing the fission process. The fine-structure - 5 peaks between 5520 and 5880 keV and 3 peaks between 5920 and 6150 keV (each 15-30 keV wide) - is interpreted as evidence of vibrational resonances in two additional shallow wells, each 400 to 800 keV deep, located just below the shelves at 5880 and 6150 respectively.

Absolute Calibration of the Photofission Spectrum of ^{238}U Near Threshold

J.W. Knowles, W.F. Mills and J.L. Gallant

In order to measure the abolute cross section of the photofission of ^{238}U, it is necessary to measure the counting efficiency of the fission chamber containing 120 target plates, each 1.8 mg.cm^{-2} thick. This efficiency was compared with that of a reference chamber containing a single target plate of $^{238}UF_4$, 197.2 μg.cm^{-2} thick. The two chambers were located in tandem in a collimated beam of ∿9.0 MeV γ-rays at the NRU reactor. The reference chamber had a previously measured efficiency of ∿99%. The absolute efficiency of the large fission chamber derived from this measurement is 0.55±0.03. This value was then used to obtain the absolute cross section for photofission of ^{238}U between 4950 and 6350 keV. In particular the peak cross sections at 5990, 6090, 6130 and 6190 keV are 4.8±0.5, 7.0±0.7, 7.4±0.8 and 5.1±0.5 mb which combine to give an average cross section of 6.0±0.3 mb over a range of 200 keV. This is in good agreement with previous low-resolution measurements (A.M. Khan and J.W. Knowles, Nucl. Phys. A179 (1972) 333).

Improvements in the Performance of a Multi-Wire Fission Chamber

J.W. Knowles and W.F. Mills

Measurements of the photofission cross section near the fission threshold, made with the bremsstrahlung monochromator at the University of Illinois, can be extended to lower energies if the coincidence resolving time between the detector of bremsstrahlung electrons and the detector of photofission events can be reduced. Reduction of the pulse rise time in the fission chamber is limited by the gas pressure needed to sustain a suitable voltage without breakdown across the insulator. For 600 volts, this pressure has been reduced in a test counter from 27 torr to 5 torr by inserting 20-μm-thick Mylar strips midway between the cathode and anode, extending 1 mm from the insulator surface into the counting volume. The greater ion mobility at the lower pressure reduced the pulse rise-time, and in conjunction with improved electronics reduced the resolving time to 4 ns. This is expected to lower the (γf) cross-section limit of measurement from 0.1 to 0.03 mb near 5 MeV in ^{232}Th and ^{238}U and thus reduce the energy at which cross sections can be measured.

Resonance Averaged Channel Radiative Neutron Capture Cross Sections

Y.K. Ho and M.A. Lone

A report on this work has been published in Nuclear Physics (A406 (1983) 1) with the following abstract:

"In order to apply Lane and Lynn's channel capture model in calculations with a realistic optical model potential, we have derived an approximate wave function for the entrance channel in the neutron-nucleus reaction, based on the intermediate interaction model. It is valid in the exterior region as well as the region near the nuclear surface, and is expressed in terms of the wave function and reactance matrix of the optical model and of the near-resonance parameters.

With this formalism the averaged channel radiative neutron capture cross section in the resonance region is written as the sum of three terms. The first two terms correspond to contributions of the optical model real and imaginary parts respectively, and together can be regarded as the radiative capture of the shape elastic wave. The third term is a fluctuation term, corresponding to the radiative capture of the compound elastic wave in the exterior region. On applying this theory in the resonance region, we obtain an expression for the average radiative width similar to that of Lane and Mughabghab.

We have investigated the magnitude and energy dependence of the three terms as a function of the neutron incident energy. Calculated results for ^{98}Mo and ^{55}Mn show that the averaged channel radiative capture cross section in the giant resonant region of the neutron strength function may account for a considerable fraction of the total (n,γ) cross section; at lower neutron energies a large part of this channel capture arises from the fluctuation term. We have also calculated the partial capture cross section in ^{98}Mo and ^{55}Mn at 2.4 keV and 24 keV respectively and compared the ^{98}Mo results with the experimental data."

An Interference Effect in the Channel Radiative Capture Process

Y. K. Ho and M.A. Lone

This work has been published in Nuclear Physics, A406 (1983) 18, with the following abstract:

"This study shows that the small thermal neutron radiative capture cross sections in ^{12}C and neighbouring nuclides are the result of destructive interference between the potential scattering wave and the resonance scattering wave near the nuclear surface, resulting in a drastic cancellation in the radial integral. The behaviour of the scattering wave function is examined, and the general condition for the occurrence of such cancellation is discussed. The expression for the channel radiative capture cross section which has been derived has the same structure as the Lane-Lynn formula but is expressed in terms of different parameters. In addition, this investigation shows that if the optical model well depth is adjusted so that the binding energy of the $p_{1/2}$ orbit in ^{12}C is kept at the experimental value, then the calculated results for the potential and channel radiative neutron capture cross section are insensitive to the value of the nuclear radius."

Total Neutron and Bremsstrahlung Yields for Electron Bombardment of Targets of Natural Elements

M.A. Lone, D. Chan, H.C. Lee and F.C. Khanna

We have calculated bremsstrahlung and total neutron yields from natural element targets of various thicknesses for electron energies up to 40 MeV using the ETRAN Monte Carlo code (M.J. Berger and S.M. Seltzer, Phys. Rev. C2 (1970) 621). Measurements of total neutron yields from selected materials using a water bath technique (M.A. Lone et al. Nucl. Instrum. Meth. 214 (1983) 333) are also planned for validation of the theoretical models.

Table 2 shows calculated results from a Ta target of an optimum thickness for bremsstrahlung yield for electrons of energies between 8 and 12 MeV. These results are in excellent agreement with those reported by Berger and Seltzer (Phys. Rev. C2 (1970) 621).

Table 2. Bremsstrahlung and neutron yields from electron bombardment of a Ta target.

E_0	Thickness	Y_B%	Y_N	E_0%	Y_B%
MeV	$g.cm^{-2}$	Forward	Per Electron	Leakage	Backward
12	4	21.7	2×10^{-5}	4.9	3.8
10	3	18.8	2.9×10^{-6}	8.5	4.1
8	2	15.5	8.5×10^{-8}	17.2	3.5

Accelerator Breeder Bibliography

B.M. Townes

A bibliography covering reports published since 1970 on aspects relevant to accelerator breeder neutronics has been given in an unpublished Technical Memorandum.

Bound Thermal Neutron Cross Sections of the Elements

V.F. Sears

In the application of thermal neutron scattering to the study of the structure and dynamics of condensed matter, a knowledge of the bound coherent and incoherent thermal neutron scattering cross sections of the elements is required. We have calculated an up-to-date table of these quantities using data from two different sources: (1) the free-atom cross sections listed in the most recent editions of BNL-325 and (2) the directly measured bound scattering lengths of the elements and their isotopes that have been collected in the data bank at Jülich. For about 25% of the elements there are significant discrepancies (i.e., discrepancies greater than twice the standard error) between the values determined from the two sets of data.

These results have been published in report AECL 7980, in which we also call attention to, and clarify, the confusion that exists in the literature concerning the sign of the imaginary part of the complex scattering length.