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MATTERS RELATED TO THE NEANDC TASK FORCES ON ^{238}U AND ^{56}FE RESONANCES

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Abstract: Following the Antwerp Conference, Task Forces were appointed by the Nuclear Energy Agency Nuclear Data Committee (NEANDC) to investigate discrepancies in the resolved resonance parameters of ^{238}U and the 1.15 keV resonance in ^{56}Fe. The ^{238}U Task Force also considered the discrepancies in the measurements of the ^{238}U capture cross-section between 1 and 30 keV. The work of the Task Forces was reviewed at the Santa Fé Conference where it was concluded that the origins of the ^{238}U discrepancies were largely understood. For ^{56}Fe it was clear that a consistent set of resonance parameters could be obtained from improved transmission measurements for the 1.15 keV resonance. However, the discrepancy between the results of capture and those of transmission remained. The work undertaken since Santa Fé on matters related to the Task Forces is reviewed. In the case of ^{238}U, particular emphasis is placed on the reanalysis and evaluation of resolved resonance parameters. In the case of ^{56}Fe, the attention is focussed on the experimental determination of the response functions of capture detectors and on the comparison of these data with calculations.

(^{238}U, resonance parameters, capture cross-section; ^{56}Fe 1.15 keV resonance, capture detectors, resonance parameters)

Introduction

The work of the NEANDC Task Forces on ^{238}U and ^{56}Fe was reviewed at the Santa Fé Conference[1,2]. This paper considers some of the work that has been undertaken since then; it is not an official report of the Task Forces but is a personal assessment by the authors of the present situation. The paper is divided into two sections which consider the problems of ^{238}U and ^{56}Fe separately.

^{238}U

The ^{238}U Task Force was set up to consider the discrepancies in (a) the neutron widths of the resolved resonances above 1.4 keV and (b) the capture cross-section in the resolved and unresolved resonance regions. At the Santa Fé Conference the main conclusions of the Task Force were

(1) The discrepancy in the neutron widths of the resolved resonances has been shown to be due to the experimental resolution functions being wider and more complex than the experimenters have assumed.
(2) The presently published values of the neutron widths are in error and so reanalysis is necessary, using shape analysis methods.
(3) It follows that all existing evaluations of resolved resonance parameters are in error. Ideally re-evaluations must wait for the reanalysis to be completed.
(4) The experimental resolution function of the best set of high resolution transmission data (Olsen et al[3]) is uncertain above 4 keV.
(5) In the longer term the following experimental work appears necessary
    (a) there is a need for measurements to give more ℓ-wave assignments for resolved resonances
    (b) higher resolution transmission measurements are desirable (e.g. cooled samples, 200/300 m flight path, 10 ns burst width, detector with improved and well known resolution function)
(6) There was evidence that the important capture cross-section data of de Saussure et al[4] were incorrectly normalised (at energies above the 6.6 eV resonance) which tends to reduce the discrepancies in the capture cross-section measurements.
(7) Further capture cross-section measurements, which emphasise new approaches and techniques and minimise corrections are still desirable.

It is worth noting that, though the main origins of the discrepancies were understood the NEANDC considered that the work of the ^{238}U Task Force would not be complete until a new recommended set of resonance parameter data was available. In consequence this section of the paper is largely about improved resolved resonance analysis of ^{238}U.

Resonance Analysis of ^{238}U

There have been very significant improvements to the resolved resonance parameter data for ^{238}U since 1985. Olsen[5] has completed a shape analysis of the transmission data of Olsen et al[3] which provides the parameters (neutron width (Γ_n) and resonance energy (E_R) assuming the statistical spin factor (g) = 1) of 676 resonances between 0.9 and 10 keV. This work was a major step forward and has provided an essential input to all other work. However, many resonances were missed in this analysis because they were not visible in the measured transmission data[+]. (Approximately 1800 s- and p-wave resonances are expected in this energy range for an s-wave level spacing of 20 eV.) A substantial fraction of these missed resonances can, however, be seen in good resolution capture data. Fig. 1 for example shows a comparison of the measured transmission data of Olsen et al[3] with some preliminary capture yield measurements of Macklin et al[6].

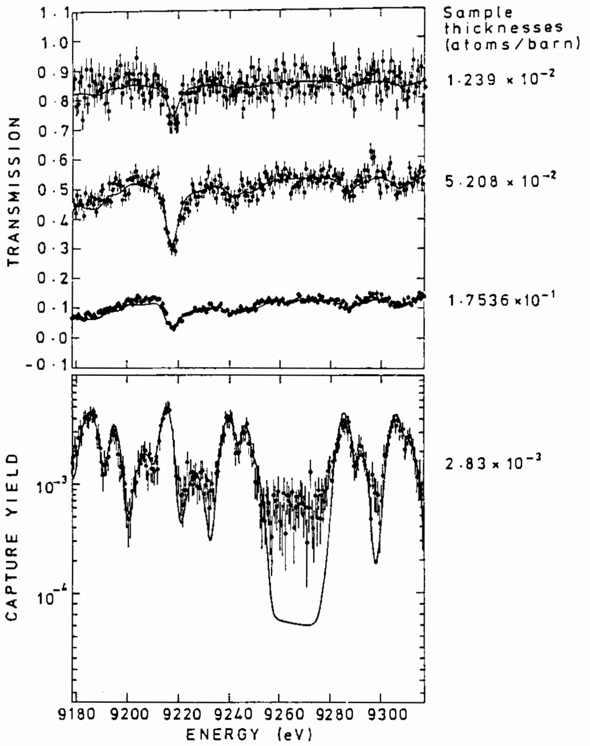

Fig. 1 Comparison of transmission measurements of Olsen et al[3] and preliminary capture yield measurements of Macklin et al[6] with values calculated from resonance parameters.

In the energy range 9180 to 9320 eV the transmission data are fitted by 6 resonances while the analysis shown requires 21 resonances. Between 9 and 10 keV ~36% of the capture cross-section is accounted for by the missing resonances. Therefore it is vital to analyse the capture yield data, using shape analysis methods, if the best set of parameters is to be obtained. However, this is very expensive in computing time because of the need to perform multiple scattering corrections as well as the necessary resolution and Doppler broadening.

The new resonance analysis of ^{238}U being performed at Harwell with the collaboration of the NEA Data Bank[7] therefore uses the code REFIT[8] which has the ability to use the shape analysis method for both transmission and capture measurements. Shape analysis of the capture data of ^{238}U has not been performed before and it is proving to be a very powerful method for obtaining accurate parameters even when resonances overlap. The analysis is being carried out in a number of stages:

(1) An evaluated list of neutron widths obtained from previous analyses of transmission data is produced.

(2) These parameters are used, assuming that the capture width (Γ_γ) is 23.5 meV*, to compute the shape of the capture yield using the version of REFIT which does a simplified multiple scattering cross-section. The shapes of the measured and computed capture yields are then compared and the resonances not seen in transmission but visible in capture are identified; neutron widths are estimated and added to the evaluated list. Care is taken in all this to ensure, by fitting the transmission data in some cases, that the estimated parameters are consistent with the transmission data.

(3) Stage 2 is repeated until all possible small levels have been identified in the capture yield data.

(4) A simultaneous fit of the transmission and capture data is performed using the version of REFIT which does a more exact multiple scattering correction and values of the Γ_n and Γ_γ are obtained as appropriate.

The initial evaluated list of resonance parameters was based on a variety of references. The subsequent analyses are based on the data listed in Table 1.

Table 1

Data being used in the ^{238}U resolved resonance analysis

Energy range	Capture data	Transmission data
0-900 eV	*de Saussure et al[4] Moxon[10]**	Olsen et al[9]
900-4000 eV	*de Saussure et al[4] Macklin et al[6]	Olsen et al[3]
4000-10,000 eV	Macklin et al[6]	Olsen et al[3]

* Data renormalised
**First few resonances only

At the present time stage 3 has been reached over the whole energy range. However, the analyses have used the data of Macklin et al kindly provided in preliminary form and as there are significant differences between these and the final data some further analysis is required. Below 4 keV, however, this should not make very significant differences to the results as the capture data of de Saussure et al[4] were given greater weight than the preliminary data of Macklin et al which were mainly used to identify the positions of small resonances.

In the energy range below ~300 eV the transmission data have been analysed to obtain values of Γ_γ, Γ_n and the effective temperature (T_{eff}) in the gas model of Doppler broadening. The average value of Γ_γ is 23.0±0.05[+] meV which is slightly lower than previous determinations, probably due to the values of Γ_n being slightly larger. The values of T_{eff} are discussed elsewhere[11]; they indicate that solid state effects may be present for the first two resonances and that

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[+] A higher resolution transmission experiment using a proton recoil detector has been performed at Oak Ridge. This together with a detailed study of the resolution function of the ORELA target will significantly improve the situation.

*Recently this value has been changed to 23.0 meV

[+] Systematic errors not included

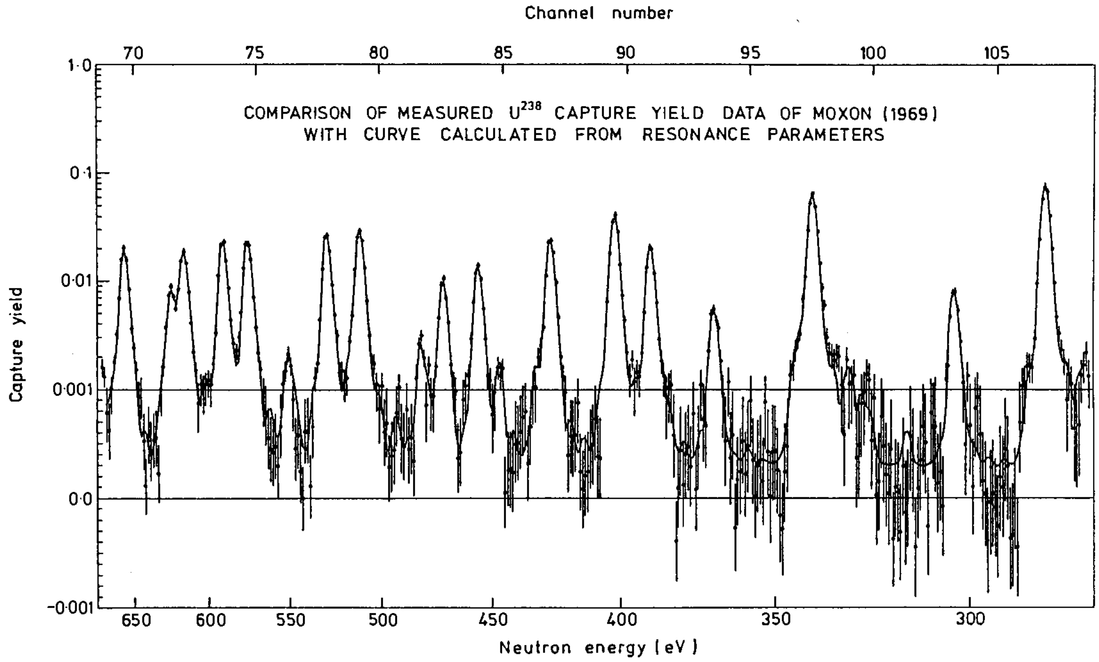

Fig. 2

T_{eff} is inconsistent with the value derived from the Debye temperature.

Fig. 2 shows a comparison of measured capture yield data with a curve calculated from the present set of resonance parameters. It should be noted that the experimental data of Moxon[9] were not used in this energy range to obtain the parameters. When overlapping resonances occur in the data they are always analysed assuming that Γ_γ is 23 meV for each resonance. In some cases, for example the "large s-wave resonance" at ~1782.7, two resonances of the same spin must occur very close together. If in this case the peak in the cross-section is analysed as a single s-wave resonance then it must have a Γ_γ value of ~46 meV. In the analysis it has been assumed that there are two s-wave resonances (Γ_n = 492.5 and 163.2 meV). (In this energy range the average $g\Gamma_n$ for p-wave resonances is expected to be ~1 meV.) Fig. 3 shows a typical problem at higher energies; two peaks are visible in the capture cross-section at ~5038 eV but only one is readily apparent in the transmission data. In the calculation shown it is assumed that the upper of the peaks at ~5040 eV has a Γ_n of 133 meV. To get a reasonable fit this resonance has to be replaced by two resonances with neutron widths ~17 meV which will hardly be visible in the transmission data. (The resonance at 5007 eV has a Γ_n value of 82 meV and produces only a small transmission dip.)

The final set of resonance parameters obtained from this analysis will provide an excellent test of parameter and resonance spacing distributions. Smith[12] has started to study the data using methods based on ladder statistics and has obtained for the s-wave levels a sequence of resonances consistent with known spacing distributions and a Porter-Thomas distribution of neutron widths. The average level spacing obtained is 20.5±1.5 eV. Fröhner[13], however, has examined the same data using the STARA code, which is based on the Porter-Thomas distribution of neutron widths, and concludes that the mean level spacing is ~22.5±1.0 eV. This value combined with a mean capture width of 23 meV permits a simultaneous fitting[14] of average

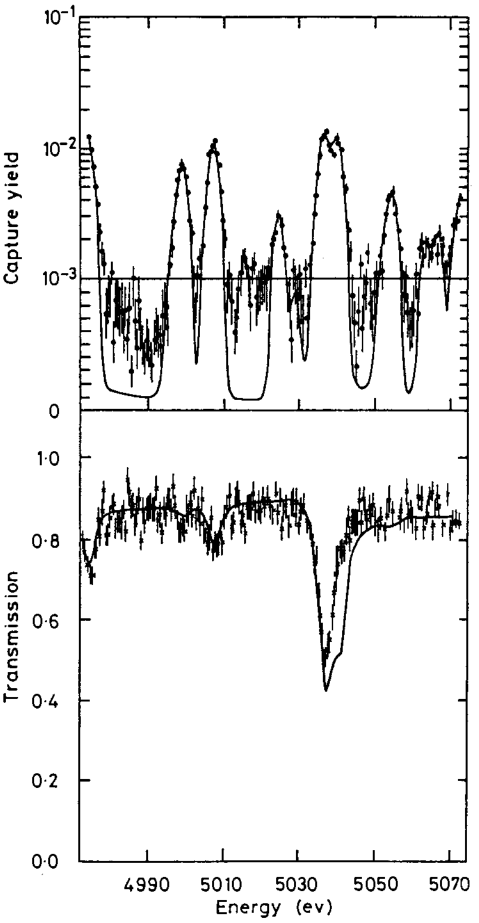

Fig. 3 Comparison of capture yield and transmission data with a curve calculated from resonance parameters.

total, capture, and inelastic scattering data using the FITACS code. This produces capture cross-section data consistent with the evaluation of Poenitz[15] up to the third inelastic threshold at 310 keV. These differences in mean level spacing need to be understood. An experiment to determine resonance spins and ℓ-values would be invaluable.

The average capture cross-section from the present parameter set can be compared with the evaluated data of Poenitz[15]. There is broadly good agreement below 4 keV but between 4 and 10 keV the difference between them progressively increases. Careful investigation shows that part of the problem is due to the use of the preliminary data of Macklin et al in the analysis. Analysis of the final data tends to reduce but not eliminate the differences. Further analysis tends to suggest that the final data of Macklin et al still requires some renormalisation and background correction and this is at present being studied. Then stage 4 of the resonance analysis will be performed and the final set of parameters obtained. Fig. 4 shows some measurements of Macklin et al in the vicinity of the large s-wave resonances at 1393.8 and 1405.4 eV which have been renormalised and background corrected. It can be seen that the calculated and measured curves are in excellent agreement over the resonances showing that (a) the gas model of Doppler broadening with an effective temperature (305.7 K) is correct in this energy range, (b) the code REFIT performs correctly the necessary multiple scattering Doppler and resolution broadening and (c) the renormalisation and background correction are necessary.

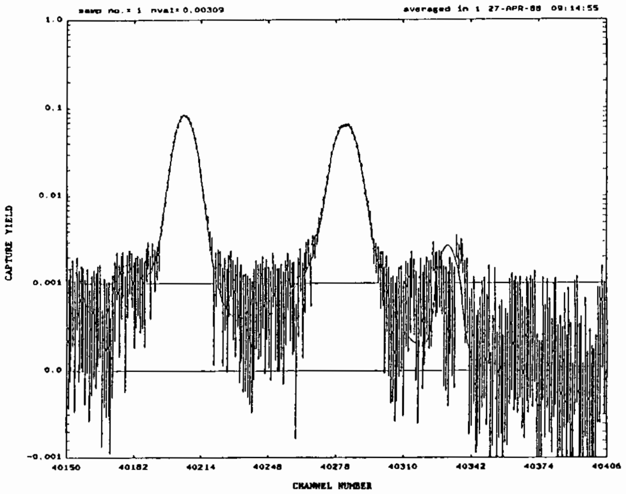

Fig. 4 Comparison of the calculated yield curve with renormalised and background corrected final data of Macklin et al in the vicinity of the large s-wave resonances at 1405.4 (Γ_n = 75.5 meV) and 1393.8 (Γ_n = 215 meV) eV.

^{238}U capture cross-section

In the past 3 years significant progress has also been made on the ^{238}U capture cross-section discrepancy. There have been new measurements by Kazakov et al[16], which cover the energy range 4-460 keV, and the unique high resolution measurements of Macklin et al[6]. The most important work on ^{238}U capture, however, has been the evaluation effort of Poenitz[15] as part of the work to obtain the standard cross-sections for ENDF/B-VI[17]. In this the ^{238}U capture cross-section has been evaluated simultaneously with the conventional standards such as the ^{6}Li(n,α), ^{10}B(n,α), Au(n,γ) and ^{235}U(n,f) cross-sections. In the evaluation great care was taken to ensure that the data base was complete and free from error. Data were corrected for known experimental errors and the generalised least squares evaluation procedure took into account the main correlations between data points for a given experiment and between experiments. For ^{238}U the average capture cross-section derived from resolved resonance parameters has been used as a "measured" cross-section. Since below 2 keV these data are assumed to be accurate to ~±2-3% they carry high weight in the simultaneous analysis. The resulting evaluated cross-section lies on the lower side of the bulk of the available measurements and is accurate to ~±2-3% or better over most of the energy range between 10 keV and 2.2 MeV. It is also consistent with the renormalised data of de Saussure et al[4] and with the unresolved region evaluation of Fröhner[14] below 310 keV which is based on total and inelastic scattering data as well as measurements of the capture cross-section. Preliminary benchmark tests by Poenitz show that it is consistent with integral evidence. Therefore, it appears that by evaluation, improvements in the consistency between integral and differential data have been achieved. However, there is probably still a need for capture cross-section measurements which emphasise new approaches and techniques and minimise corrections. The spread in measured data is still unacceptably large and an evaluation which lies to one side of the data base generates unease particularly for an important cross-section like ^{238}U(n,γ).

Conclusions on ^{238}U

Matters related to the work of the NEANDC Task Force on ^{238}U have been discussed. The origin of the discrepancies in the ^{238}U resonance parameters is now understood and the work to obtain a complete set up to 10 keV is in progress. Analysis at higher energies needs to be encouraged. The new set of parameters will provide an excellent test of the resonance spacing and parameter distribution functions. Spin assignments of resonances, however, remain a problem and further measurements are required.

The spread in measured capture cross-section data remains unacceptably large but improved evaluation techniques have produced a data set which is consistent with integral measurements in fast reactors. There is still a need for better differential measurements which emphasise new approaches and techniques and minimise corrections.

The 1.15 keV Resonance of ^{56}Fe

Transmission Experiments

The analysis of the Geel and Harwell transmission measurements of the 1.15 keV resonance being not yet completed, the best up-to-date estimate of the 1.15 keV resonance parameters is still that derived with the code SAMMY from a series of runs performed at ORELA on several sample thicknesses[2]. These data are: $\Gamma_n = 61.7 \pm 0.9$ meV and $\Gamma_\gamma = 574 \pm 40$ meV, from which a capture area $(g\Gamma_n\Gamma_\gamma/\Gamma) = 55.7 \pm 0.8$ meV is calculated. This value will be taken as a reference in the rest of this paper. It is in fact our opinion that, for this particular case (and probably for structural materials in general), present state-of-the-art capture measurements can not compete with transmission as far as the precision of the derived resonance parameters is concerned. Therefore, the value of the capture area given above should be looked at as an ideal benchmark for testing capture techniques and/or detectors. Also measurements of the angular distribution of scattered neutrons[18] and primary capture γ-rays[19] have unambiguously shown since long that the 1.15 keV resonance has $J^\pi = 1/2^-$. This is important since it implies that capture γ-rays are distributed isotropically.

Capture Experiments

It is well known that the capture measurements performed a few years ago at Geel[20,21] and Oak Ridge[22] using the pulse height weighting technique in conjunction with C_6D_6 or C_6F_6 detectors and normalizing to Ag or Au capture, yielded values of the capture area which were from 17% to 23% larger than the transmission value given above. This situation, which was in fact at the origin of the present task force, had not essentialy improved at the time of the Santa Fe Conference. However, considerable progress has been achieved in the last two years. First of all R. Macklin[23] has elegantly avoided the problem of normalization to Ag or Au capture by a self-calibrating method which makes use of a thick laminated Fe sample. In this way he has been able to obtain a value of the capture area $(g\Gamma_n\Gamma_\gamma/\Gamma) = 55.5 \pm 0.6$ meV, in excellent agreement with the transmission value. More substantial progress in understanding the reasons of the discrepancy has been realized recently both on the experimental and on the calculational side, and will be described in some detail in the following section.

The Weighting Method

This section is entirely devoted to the weighting method both because it is at the basis of the measurements yielding discrepant results and because it is the most widely used and accepted technique in the field of resonance neutron capture. Let us recall briefly its principle.

The weighting function W(E) for a given detector configuration is defined by the following system of equations:

$$\int_0^\infty R(E,E_\gamma)\,W(E)\,dE = E_\gamma \qquad (1)$$

where $R(E,E_\gamma)$ is the detector response function, i.e. the probability that a γ-ray of energy E_γ gives rise to a pulse of amplitude E.

It can be easily shown that , if Eq.(1) holds for any E_γ, then the following equality is true:

$$\int_0^\infty C(E)\,W(E)\,dE = E_x = S.E. + E_{kin} \qquad (2)$$

where C(E) is the pulse height distribution due to the capture spectrum and E_x is the Q-value of the reaction, equal to the neutron separation plus its kinetic energy. In other words, after proper weighting one achieves a capture detection efficiency independent of spectrum shape and multiplicity and only proportional to the total γ-energy emitted.

If $R(E,E_\gamma)$ is known for a series of E_γ values covering the whole range of interest for neutron capture, then W(E) can be obtained by solving the system (1). What is done in practice is to approximate W(E) with an nth degree polynomial in E, whose coefficients are determined via a least-squares fit from the system (1).

In all capture experiments published up to now, the set of response functions was obtained by a Monte Carlo simulation of the detection process. Only recently an experimental method[24-26] has been developed in Geel for determining the response functions for a number of γ-rays in the range 0.8-9.4 MeV. A summary of it will be given in the following.

Experimental Determination of the Weighting Function

The method consists of measuring gamma transitions from (p,γ) resonance reactions with a Ge detector, both in singles mode and in coincidence with the detector to be calibrated, in this case a cylindrical C_6D_6 liquid scintillator. When capture mainly proceeds through a few strong two-step cascades, as is often the case in resonances of light nuclei, the C_6D_6 efficiency for one γ-ray can be derived via the coincidence method, i.e. by calculating the ratio between the peak areas of the complementary γ-ray in the coincident and singles Ge spectra. Similarly, the response function of a given γ-ray is obtained from those C_6D_6 pulses which are in coincidence with the full energy peak of the complementary transition.

The experimental setup is shown in Fig.5.

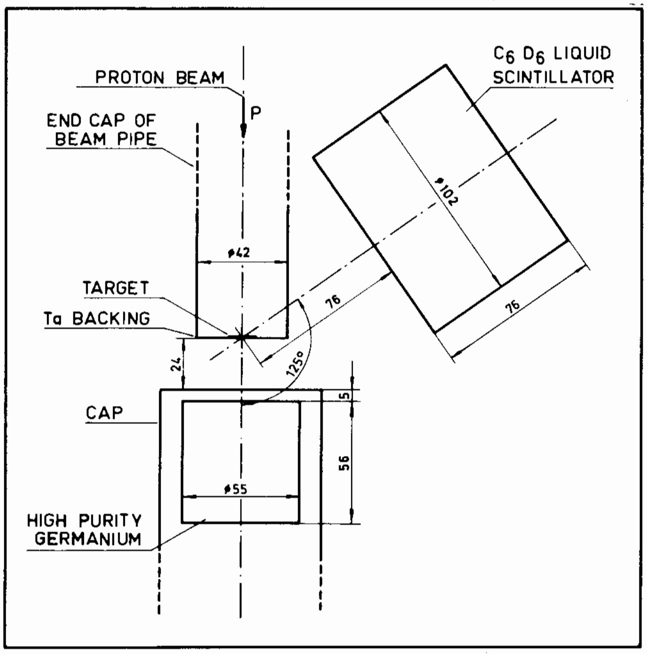

Fig. 5 Top view of the experimental setup. Dimensions are in mm.

The proton beam was provided by the 7 MV CN-type Van de Graaff operated in its DC mode. Targets of ^{26}Mg at proton energies of 1001 and 2220 keV, of ^{30}Si at 1398 keV and of ^{34}S at 1211 keV were used. In order to determine the efficiency, the raw data must be corrected for contamination of cascades of higher multiplicity and for angular correlations.This last correction was found negligible for all cascades considered.

Sixteen measured values of the absolute efficiency of the C_6D_6 scintillator of Fig. 1, operated with a 100 keV bias, are plotted *vs* energy in Fig. 6 where the continuous line is a parabolic fit to the data and the dotted line is the efficiency calculated according to the known cross sections for the interaction of γ-rays with matter, assuming a point source and neglecting any effect of the environment. One may notice that, in contrast to calculations, the measured efficiency for γ-rays in the range 0.5-10 MeV does not decrease with energy but stays approximately constant.

The values of the efficiencies are important because, being the integrals of the response functions, they are used for normalizing the $R(E,E_\gamma)$ curves entering system (1). These response functions have been determined for 13 out of the 16 γ-rays of Fig.6. For high-energy transitions the disagreement with the calculations is striking: many more low-energy pulses are observed than had been foreseen in the simulations. A weighting function calculated from system (1) using this experimental data set is plotted in Fig.7 (full line) together with that based on the old Monte Carlo simulation and used up to now in neutron capture measurements (dashed line). Both curves, which are normalized to the same value at channel 10 (E=0.5 MeV), are 4th degree polynomials.

The setup used in neutron capture is different from that of (p,γ) measurements since it consists of two C_6D_6 detectors of same size as in Fig.5 placed symmetrically at 90° with respect to the neutron beam, looking at a sample of 8 cm diameter at a distance of 5-6 cm from its centre. If one assumes that, in spite of these differences, the weighting function is the same for both setups, one can recalculate the parameters of the 1.15 keV resonance.This was done by using the same data base of ref.[21] but replacing the calculated W-function with the experimental one. The value found for the capture area: $(g\Gamma_n\Gamma_\gamma/\Gamma)=57.1\pm2.1$ meV is 16% lower than the old one and agrees within the errors with the reference value from transmission.

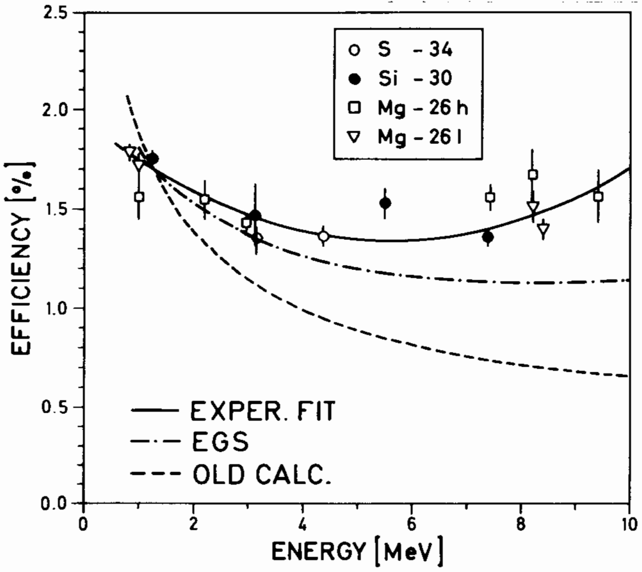

Fig. 6 Absolute efficiency of the C_6D_6 scintillator plotted *vs* γ-ray energy for one experimental and two calculated data sets.

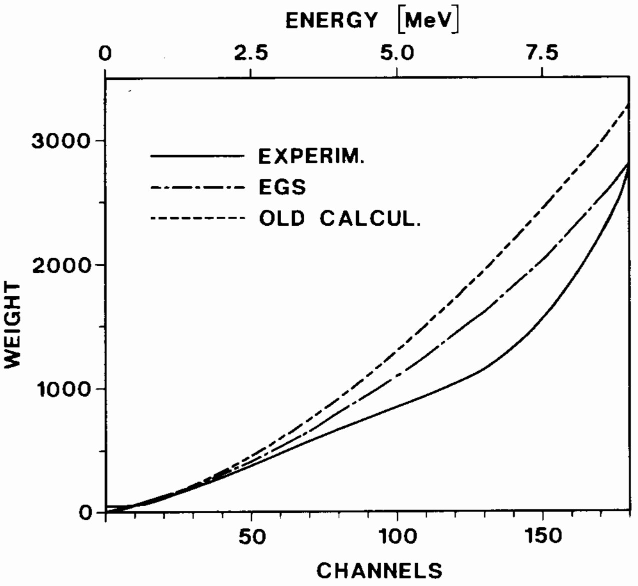

Fig. 7 Weighting functions corresponding to 150 keV bias, normalized to same value at channel 10.

EGS Calculations of Detector Responses

The success of the experimental approach in reproducing the transmission value for the 1.15 keV resonance and the large discrepancy between the experimental and the calculated response functions have stimulated a new series of calculations. These have been carried out by F. Perey et al.[27] with the electron gamma transport code EGS from Stanford Linear Accelerator. The main improvements of this widely used code over the old ones is a correct treatment of the electron transport and the possibility of studying in a detailed way the influence of any material surrounding the source-to-detector configuration. In this respect the only limitation is the amount of computer time needed for obtaining a reasonable statistics.

We refer the reader to ref.[27] for a complete and up to date survey of the work carried out. As far as the Geel (p,γ) data are concerned, the EGS code has met with a considerable success in calculating high-energy response functions which are much more similar to the experimental ones than the results of the old calculations. The agreement is however not yet satisfactory since the low pulse height region of the response functions (with the exception of the part below 0.5 MeV) is still 15 to 20% lower than the experimental data. This situation is reflected in Fig.6 where the absolute efficiency is plotted *vs* energy also for the EGS results (dash-and-dot line): one can notice that these data are in fact intermediate between the experiment and the old calculations.

Also, F. Perey has calculated response functions and efficiencies for the Geel neutron capture setup and he has found that these quantities are strongly dependent on sample thickness. He has in fact calculated a weighting function for each thickness of interest: the one corresponding to the 0.5 mm thick Fe sample used in the normalization to Ag and Au capture is also plotted in Fig.7. Here again we notice that the W-function based on EGS is intermediate between the experiment and the old calculations. A value of the 1.15 keV capture area computed with this W-function is given in Table 2 and compared to the previous values: it is not surprising that it falls about midway between the two previous results.

The response function of the 6.13 MeV γ-ray from $^{19}F(p,\alpha\gamma)$ has been measured in Harwell by D. Gayther et al.[28]using 400 keV protons and a C_6D_6 scintillator of 10 cm diameter and 5 cm height. The EGS code has been very successfull in reproducing this response function; however, such an agreement concerns only its *shape* and not its *absolute* magnitude since, in contrast with the Geel (p,γ) data, the Harwell singles measurements do not allow any absolute calibration. Also, Gayther has measured the 1.15 keV capture area using two of these detectors and normalizing to the 4.9 eV Au resonance. The results are given in the last column of Table 2 for the W-function calculated with the old GAMOC code and with the EGS code, and for the experimental Geel function. The authors state that the latter has been modified to allow for the smaller volume of the Harwell detectors. The Harwell data set is in remarkable agreement with the Geel one with the exception of a systematic shift of about 3%.

To conclude, the EGS calculations have pointed out the great role played by the environment and in particular by the sample acting as a source of high-energy electrons and positrons which can subsequently escape and be detected with high efficiency in the scintillator. However, on a quantitative basis, the agreement between experiment and simulations is still far from being satisfactory: the weighting functions calculated with EGS for the rather thin samples used in the Fe to Au/Ag normalization yield values of the 1.15 keV capture area which are 7-10% larger than the benchmark value.

Table 2: Values of the capture area of the 1.15 keV resonance obtained in the Geel and Harwell normalizations to Ag and Au capture, respectively, using three different weighting functions.

Measurement	Weighting Function	$g\Gamma_n\Gamma_\gamma/\Gamma$ (meV)	
		Geel	Harwell
Capture	Old Code	67.4±2.9	65.0±3.3
Capture	EGS Code	61.8±2.3	59.5±3.0
Capture	Experiment.	57.1±2.1	55.8±2.8
Transmission (Oak Ridge)		55.7±0.9	

Further Experimental Tests

Some further experimental investigations were carried out in Geel based on singles rather than coincidence measurements and using as a source of almost monochromatic high-energy γ-rays the resonance produced in the reaction $^{30}Si(p,\gamma)$ at E_p=0.62 MeV. The compound ^{31}P state corresponding to this resonance decays to the ground state with a 95% branching ratio[29] via a transition of energy E_γ=7.898 MeV. The efficiency of the C_6D_6 liquid scintillator for this γ-ray was measured relative to that of a calibrated ^{60}Co source by comparing the ratio of the counting rates of the scintillator for the two gamma sources to the corresponding ratio of the full peak areas in the amplitude spectra of a coaxial Ge diode. Both detectors were placed symmetrically at an angle of 35° with respect to the proton beam direction, their entrance window being at 25 cm from the target. The relative full peak efficiency of the Ge detector for the transitions under investigation could be determined by measuring the decay of the $^{30}Si(p,\gamma)$ resonance at E_p=1.398 MeV, dominated by the two-step cascade consisting of the 7.383 and the 1.266 MeV γ-ray, with well known intensities. The low energy transition can very well represent the two ^{60}Co lines since its energy is almost coincident with their average. Moreover, the difference in efficiency between 7.383 and 7.898 MeV was estimated from data of other ^{30}Si resonances. After subtracting the contribution of the contaminant γ-rays present in the decay of the E_p=0.62 MeV resonance, the efficiency ratio for C_6D_6 was $\varepsilon(7.90)/\varepsilon(1.25)$= 1.02±0.05, a value which agrees with the results of the coincidence method. The absolute values of the efficiency could also be determined since the ^{60}Co source used was calibrated to better than 1%; in particular, it was found that the measured efficiency at 1.25 MeV coincides within the errors with that calculated from the known cross sections, in agreement with the data of Fig.6.

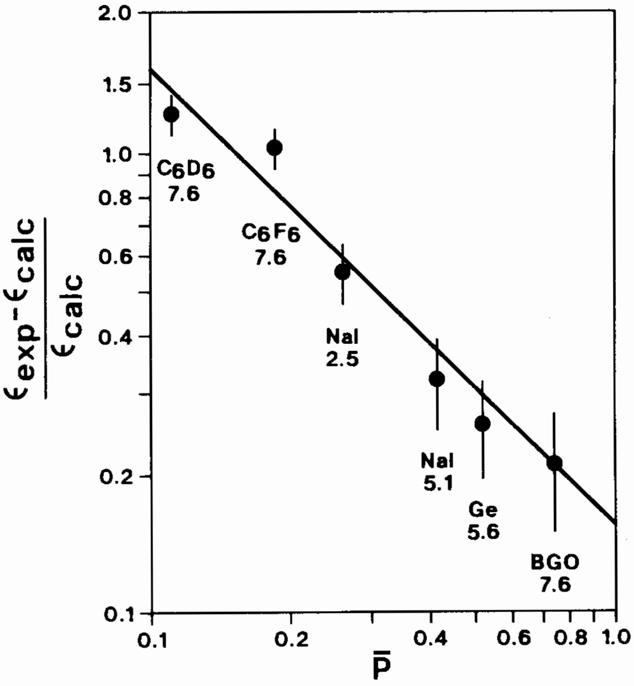

Fig. 8 Relative difference between experimental and calculated efficiency plotted versus the intrinsic efficiency $\bar{P}$ for the γ-ray of energy E_γ=7.898 MeV. Detector composition and thickness is given beneath each point.

In additional runs the C_6D_6 scintillator was replaced by other detectors and similar intercomparisons were carried out. The results are summarized in Fig.8 where the relative difference between the experimental and calculated efficiency for the 7.898 MeV transition is plotted *versus* the calculated intrinsic efficiency $\bar{P}$ of each detector. This last quantity is defined as $\bar{P}=\langle 1-\exp(-\mu d)\rangle$, where μ is the total attenuation coefficient and d is the path length through the detector. The plot shows that the effect found in the C_6D_6 scintillator, namely a measured efficiency larger than expected for high-energy γ-rays, is common to all detectors but decreases with $\hat{P}$. In fact, by fitting the data points with a function of the type $Y = aX^b$, one gets $b = -0.99 \pm 0.11$, in good agreement with unity. Since $\varepsilon_{calc} = (\Omega\hat{P})/4\pi$, where Ω is the source solid angle subtended by the entrance face of each detector, one can write $(\varepsilon_{exp} - \varepsilon_{calc}) \sim \Omega/4\pi$. This means that the "unknown" radiation responsible for the difference between experimental and calculated counting rate has an efficiency independent of $\hat{P}$: as a consequence, it cannot consist of γ-radiation but mainly of electrons and positrons which have of course a 100% efficiency. Tests to check this hypothesis in a more direct way are foreseen.

A second test consisted of measuring the relative efficiency of the C_6D_6 detector for the same E_γ=7.898 MeV γ-ray as a function of backing thickness. The geometry was that shown in the lower and right-hand side of Fig. 9, reproducing the neutron capture setup: up to three Ta disks each 0.3 mm thick were added to the normal backing. Normalization to the same number of captures was achieved by measuring the full peak area of the 7.898 MeV transition in the Ge spectrum. The results, plotted in Fig.9, show a very slight increase of the efficiency with thickness: for a total additional thickness of 0.9 mm Ta, only a 7% increment of counting rate is observed. It is interesting to note that, after weighting, even this small increase disappears. These findings are indirectly confirmed by the success of Macklin[23] in reproducing the transmission value of the capture area with his self- calibrated capture measurement. In fact, Macklin compares the counting rate of a 0.5 mm thick Fe sample to that of a laminated sample of 4.5 mm total thickness: his results are only correct if the detection efficiency is not appreciably dependent on sample thickness. On the other hand some EGS calculations[27] performed for thicknesses smaller or equal to 0.3 mm (see Fig.9) point to a much higher slope of the efficiency *vs* thickness curve.

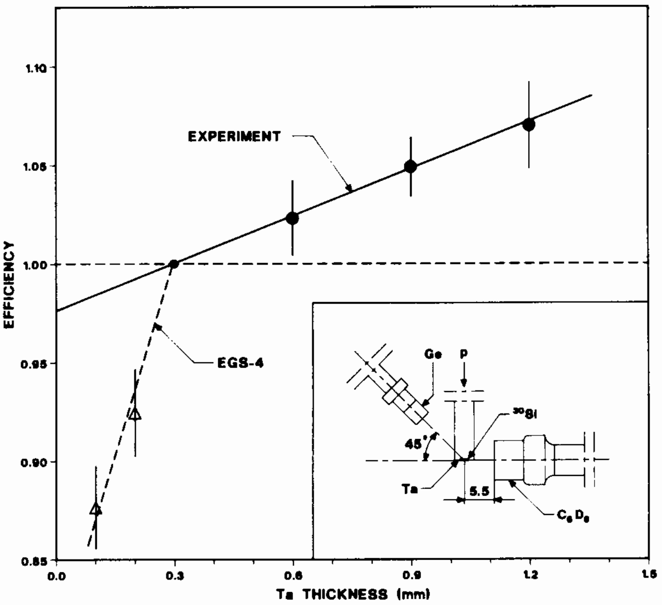

Fig. 9 Comparison of measured and calculated values of the relative efficiency plotted *vs* the thickness of Ta backing. Data are normalized to unity at t=0.3 mm.

Finally, a test was performed of the influence of the canning which, in the Geel detectors, consists of 2 mm thick aluminium walls and a teflon expansion tube full of scintillator. The test consisted of replacing the C_6D_6 with an uncanned plastic scintillator and measuring the count rate of this detector with and without the canning, in the geometry of Fig. 9: an increase of 10% due to the canning was observed. The above tests on the influence of backing and canning were performed in the last few weeks and their results should be considered as preliminary.

Discussion

It is undoubtful that a major progress has been achieved in the last two years in the understanding of the capture-to-transmission discrepancy of the 1.15 keV resonance. It is now clear that the crux of the problem lies in the inability of the capture techniques applied up to now to deal correctly with such large differences in spectrum shape as those met when comparing ^{56}Fe to Ag or Au capture. This effect was suspected since a number of years by some of us[20,21] but it could not be proved at the time.

On the other hand, it is difficult at this stage to draw any definite conclusion since the matter is not yet settled and work ist still going on in various laboratories participating to the task force. However, some guidelines for future work can be indicated.

1) There is first of all a problem with the experimental determination of the weighting function: is it correct to apply to the neutron capture case the weighting derived from (p,γ) measurements and, in any case, what is the systematic uncertainty introduced by this procedure? Although the transfer from (p,γ) to (n,γ) can be justified *a posteriori* by the agreement of the derived capture area with the benchmark value, one should independently investigate this point. For this reason it is planned to repeat in Geel the (p,γ) exercise with a setup approaching as much as possible the neutron capture case. The only unavoidable difference lies in the γ-ray source which is in one case a thin layer of a few mm diameter on a Ta backing and in the other an Fe sample with a diameter an order of magnitude larger. Therefore the influence of the gamma source on the weighting should be carefully studied both by calculations and by experimental tests. Always in the same line of investigations, one should clear up the apparent discrepancy shown in Fig. 9 between the results of the EGS code and those of the experiment.

2) In presence of a sound experimental method of detector calibration, Monte Carlo calculations performed in order to obtain a weighting function are in principle not needed. On the other hand, these simulations are essential in order to understand in quantitative terms the physics of the detection process and to be able to extrapolate the experimental results to slightly different configurations. Unfortunately, EGS calculations do not yet reproduce exactly the experimental results: to understand what is wrong, one should investigate with these simulations the influence of the various parameters of a

given configuration (sample thickness,detection angle and distance, surrounding material) in close connection with the experimental tests.

3) Neutron capture in the 1.15 keV resonance was measured in Geel some time ago also with three different Moxon-Rae detectors[30]. Similarly to the old results of the weighting technique, the values of the capture area obtained were 14 to 16% larger than the benchmark value, a fact which could not be explained at that time. These results were based on efficiency-*vs*-energy curves mainly derived from *ad-hoc* Monte Carlo simulations of the detection process. In the light of our experience with C_6D_6 and C_6F_6 detectors, it is very likely that these calculations are unreliable and should be replaced by the EGS code. In parallel, the efficiency curve should be experimentally determined with the (p,γ) method.

4) It is now clear that in the last twenty years or so many capture measurements were carried out with a technique (C_6F_6 or C_6D_6 detectors plus the weighting method) which was not correctly known. It is now time to critically revise the past experiments and to decide which ones should be reanalysed (a possibility if the amplitude information was preserved) or commpletely repeated. This task is clearly beyond the scope of the present paper; however, this Conference offers a good occasion for starting a discussion about this problem.

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