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Status of Neutron Nuclear Data for Important Fast Reactor Structural and Coolant Materials

B. Schatz

GESELLSCHAFT
FÜR
KERNFORSCHUNG M.B.H.

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Gesellschaft für Kernforschung m.b.H., Karlsruhe

Abstract

In this report the present status of our knowledge of the neutron nuclear data for the most important structural materials nickel, iron, chromium and the predominant coolant material sodium is presented. For this purpose the available experimental information on these data is reviewed. In particular the improvements in the data situation attained in the last years are examined. Elastic scattering angular distributions are not considered. Essentially only the literature references compiled in CINDA + 71 including its Supplement 2 were taken into account.

Stand der Neutronenkerndaten der für schnelle Reaktoren wichtigen Struktur- und Kühlmaterialien

Zusammenfassung

In diesem Bericht wird der gegenwärtige Stand unserer Kenntnis der Neutronenkerndaten für die wichtigsten Strukturmaterialien Nickel, Eisen, Chrom und das vorherrschende Kühlmaterial Natrium dargestellt. Zu diesem Zweck wird ein Überblick über die für diese Daten vorhandene experimentelle Information gegeben. Insbesondere werden die in den letzten Jahren erreichten Verbesserungen in der Datensituation beleuchtet. Elastische Winkelverteilungen werden nicht betrachtet. Im wesentlichen werden nur die Referenzen berücksichtigt, die in CINDA + 71 nebst Supplement 2 zusammengetragen sind.

+ CINDA - Computer Index on Nuclear Data

I. Introduction

Before analyzing the situation about the experimental data of the structural and coolant materials in more detail it might be worthwhile to have some idea of the requirements from the side of reactor physicists. For this purpose in the following table the requests for the most important cross section types of the materials considered here are summarized. They were taken out of the RENDA-list from 1970 in which the requests for neutron nuclear data measurements are compiled and regularly updated. RENDA contains not only the material and the data type for which measurements are needed but also the energy range and required accuracy and also a priority assignment.

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Material	Requested data type	Energy range	Accuracy requested in RENDA 70	number of requests
Cr and Cr-isotopes	capture cross section	1 keV-600 keV	10 - 20 %	5
	(n,α) cross section	3 MeV- 15 MeV	20 - 30 %	3
	(n,p) cross section	threshold-14 MeV	10 - 30 %	2
	differential elastic scattering cross sect.	1.5 - 15 MeV	10 - 20 %	3
	differential inelastic scattering cross sect.	500 keV - 10 MeV	10 %	1
Fe and Fe-isotopes	capture cross section	1 keV -200 keV	10 - 15 %	4
	(n,α) cross section	threshold-15 MeV	20 %	4
	(n,p) cross section	threshold-15 MeV	10 %	3 for Fe56 5 for Fe54
	differential elastic scattering cross sect.	1 keV- 16 MeV	5 - 20 %	6
	differential inelastic scattering cross sect.	threshold-14 MeV	2 - 10 %	6
Ni and Ni-isotopes	capture cross section	100 eV - 1 MeV	10 - 20 %	7
	(n,α) cross section	threshold- 15 MeV	10 - 20 %	4
	(n,p) cross section	threshold- 15 MeV	10 %	3 for Ni58 2 for Ni60
	differential elastic scattering cross sect.	10 keV - 16 MeV	10 - 20 %	6
	differential inelastic scattering cross sect.	threshold-10 MeV	5 - 10 %	3
Na	capture cross section + Res. par.	100 eV - 800keV	10 %	4
	differential elastic scattering cross sect.	2 - 15 MeV	5 - 10 %	4
	differential inelastic scattering cross sect.	2 - 15 MeV	10 %	4

The requests for differential elastic and inelastic scattering cross sections refer in many cases to requirements for shielding calculations.

The accuracy requirements of fast reactor physicists have not been met so far. In individual modern measurements sufficient high accuracies are attained due to the considerable refinement in experimental technique in the last years. One has, however, to be aware of the fact that the data sets recommended for fast reactor calculations have in general larger uncertainties than the measurement series on which the preceding evaluation is based. This is mainly due to the differences between different measurement series which are often larger than the uncertainties of each individual measurement. Since the statistical errors in modern measurements are generally small this suggests that in the individual measurements still unknown errors of a systematic nature exist which exceed the errors estimated by the author.

The fast breeder reactor is the reactor type that is most affected by the nuclear data uncertainties over the energy range of interest to fission reactors i.e. 1 keV - 1 MeV and it has not the benefit of considerable past operating experience as for example the thermal reactor. For design and operation of fast reactors the capture cross section is the most important cross section type of the structural materials, for the absorption of the cladding should be kept as small as possible in order to keep the fuel cycle as economic as possible. The high absorption cross section of Mo or Nb e.g. is the reason why one is aiming to avoid an admixture of Mo in the cladding. Such an admixture may have an important influence on the nuclear parameters of fast breeder reactors.

The most important structural materials for fast reactors are from the point of view of absorption in these materials Ni, Fe, Cr. They are components of the most usual cladding and structural materials but are contained in different fractions and with varying additional admixtures, e.g. Inconel 625 contains 62% Ni, 22% Cr, 3% Fe, 9% Mo, 4% Nb, whereas Incoloy 800 contains 48% Fe, 32% Ni, 20% Cr and both have been considered as possible alternatives in steam-cooled fast breeders. In thermal reactors they are not in commen use since they show a too strong absorption at thermal energy in comparison to other materials like Zr.

Apart from the capture cross section the most important data of the structural materials are the cross sections for the scattering processes in fast reactors, in particular the inelastic scattering cross section and the energy distributions of the inelastically scattered neutrons. The inelastic scattering process is more effective than the elastic scattering and therefore in fast reactors the inelastic scattering gives the main contribution to the slowing down of the fast fission neutrons.

Concerning the coolant materials first of all one can say that the heat transfer is an essential problem by constructing fast breeder reactors since this reactor type has a core of relative small size but high power density. Sodium ist one of the most appropriate coolant materials because of its high thermal conductivity and heat capacity. It was used therefore as cooling in the first fast reactors constructed like the Dounreay reactor in the United Kingdom, the BOR 60 in the USSR, Rapsodie in France, the EBR I and II and the EFFBR-Reactor in USA. But also in modern fast breeders it is in use or is planned to be used, namely in Phenix in France, in the PFR in Great Britain, the BN 350 and 600 in USSR, the Westinghouse, the General Electric, the Atomics International Reactors in USA and in the SNR in the Debenelux-countries. The american types and the SNR are only designs up to now.

As alternatives to cooling with sodium a number of groups considered steam and gas as fast reactor coolants. In the latter case helium plays the most important role, but only design studies and tests of some components were performed for He als coolant in fast reactors. In Sweden the appropriateness of heavy water steam cooling was investigated. Light water steam as cooling was assumed for the Karlsruhe D1 design study and for studies in the United States. Some experimental studies on the neutronics behaviour of such a design have been made e.g. in the SNEAK-facility in Karlsruhe. The United Kingdom has made similar studies. These are only some examples in order to show which materials were discussed in the last years as suitable proposals for coolant materials.

In presenting here the status of nuclear data for the most important coolant materials we shall confine ourselves with highest priority to sodium.

II. Resonance neutron nuclear data for the structural materials Chromium, Iron, Nickel

It is common to these materials that they are composed of more than one isotope.

Natural chromium consists of /122/	4.31 %	Cr-50
	83.76 %	Cr-52
	9.55 %	Cr-53
	2.38 %	Cr-54
natural iron of /122/	5.82 %	Fe-54
	91.66 %	Fe-56
	2.19 %	Fe-57
	0.33 %	Fe-58
and natural nickel of /122/	67.8 %	Ni-58
	26.2 %	Ni-60
	1.19 %	Ni-61
	3.66 %	Ni-62
	1.08 %	Ni-64

For the description of the resonance cross sections this fact plays an important role also in the case, if there is only one main isotope like for natural chromium and iron and if the admixtures of the other ones are very small. But the resonance properties of these small admixtures differ from those of the main isotope. It may be for example that they have different level densities as it is the case for the Cr-isotopes, where the level density in the compound nucleus of Cr-53 is much larger than that of the compound nucleus Cr-52. The consequence is that the cross section behaviour in the resonance region is dominated rather by the Cr-53 resonances than by the Cr-52 resonances and this in spite of its small portion in natural chromium. These intermediate mass nuclei like Ni, Fe, Cr exhibit commonly narrow, predominantly capture higher l-wave resonances superimposed on the very broad, predominantly scattering, s-wave resonances. In addition the interference among the s-wave resonances is rather strong. These two facts make the interpretation of the observed cross section data in the resonance region, their correction and parameter analysis much more difficult. Last but not least this is reflected in the disagreement between different data sets in the resonance region. Below the lowest threshold of the inelastic scattering process on the stable isotopes in the structural materials the total cross section is almost

equal to the scattering cross section, the capture cross section giving only a small contribution. Therefore the experimental transmission data are usually analyzed by the multilevel approximation to the R-Matrix theory with only a single open channel for elastic scattering. The measured capture data are in general interpreted by a superposition of single level Breit-Wigner terms. The results of the cross section fits performed by several authors are shown in Table I, II, III for the stable Cr-, Fe-, Ni-isotopes respectively.

Resonance neutron nuclear data for chromium

The first investigation of resonances in Cr was done by Melkonian /1/ in 1953. He measured σ_T on natural chromium between 0.015 eV and 10 keV and observed one resonance at 3.8 keV. He suggested in order to explain the cross section behaviour at lower energies that it should belong to Cr-53. From an area analysis he assigned Γ_n = 1620 eV. In comparison to later measurements of Hibdon /2/ this seemed too high. Hibdon performed in 1957 transmission measurements with samples of natural chromium and highly enriched (90%) Cr-53-samples covering the energy range from 3 - 410 keV. The energy spread in this measurement was very small increasing from 300 eV to 700 eV with increasing neutron energy.

He identified the resonances detected between 4 and 11 keV to be Cr-53 resonances by measuring with the enriched Cr-53 sample. The resonances between 11 and 50 keV were not determined isotopically. The range 138 - 152 keV was interpreted by Hibdon by four nearly equally broad s-wave Cr-52 resonances. As later measurements of Bowman /6/ have shown this interpretation is very probably wrong. Neutron widths were determined by Hibdon only for some of the most important resonances apparently belonging to Cr-52.

One year later Coté et al. /3/ could confirm Hibdon's observations that below 15 keV there is no resonance structure in Cr-52 and Cr-54.

They found one resonance in Cr-50 at 5.5 keV and with the assumption that the capture cross section of Cr-50 at thermal energy is entirely due to this resonance they could assign a capture width of $\Gamma_\gamma = 2.9$ eV to this resonance. They made their measurements with four samples enriched in each of the four stable isotopes of natural chromium. But they had a broad energy resolution. and measured only in the low keV-region.

In 1964/65 a group in Oak Ridge /4/ performed transmission measurements on an enriched Cr-53-sample in the energy range between 2 and 60 keV with an energy resolution of $\leq 2\%$, i.e. an energy spread between 40 eV and 1.2 keV. An area analysis was made for the data without determining the spin of the resonances. Therefore, only values for the quantity $g \cdot \Gamma_n$ could be extracted from the analyzed measured results. The most extensive and systematic resonance investigations for Cr-isotopes were performed at Duke University /5/. Their measurements coverthe energy range from 1 to 150 keV. The energy spread in these measurements is ranging from 1 keV at several keV to about 5 keV at 150 keV, that means the resolution was worse than in Hibdon's measurements. They used samples enriched in the even stable isotopes of natural chromium. The main Duke results are the following ones: The resonance structure in the total cross section in the range 3 - 11 keV is believed to be due to one very wide resonance in Cr-50 and to several more closely spaced resonances in Cr-53 (in accordance with Hibdon who could assign the Cr-53 resonances). The resonance at 23 keV (Hibdon has found one at 24 keV without any isotopical assignment) is identified to belong to Cr-54. The cross section structure between 130 and 160 keV which was interpreted by Hibdon by four equally spaced s-wave resonances in Cr-52, is according to their measurements very probably due to one large Cr-52 s-wave resonance at about 140 keV superimposed by some smaller Cr-52 p- and/or d-wave peaks and some Cr-53 resonances.

But it becomes not clear from their measurements if all the small peaks observed by Hibdon are true resonances. Bowman et al. /6/ have extended in 1962 the Duke investigations with a better energy resolution of about 1 keV by measuring from 85 keV to 650 keV on a sample enriched in Cr-52. For the narrower resonances the neutron widths of Hibdon and Bowman are in good agreement, for the broader ones Bowman's values are consistently larger than Hibdon's. This can be seen in Table Ib where the resonance parameters of Cr-52 are given.

In 1966 no capture widths were known except for the 5.5 keV resonance in Cr-50; no resonance parameters were known for Cr-50, Cr-54 above about 100 keV; for Cr-53 only the parameters of the first resonance at 4.3 keV were known; Cr-52 was well investigated but the spin assignment of the resonances was often lacking.

In order to close these gaps several transmissions and also capture measurements were performed in the last years. The transmission measurements are the following ones:

Farrell et al. /7/ from Duke University in 1966

Measurements up to 600 keV on an enriched Cr-50 sample with an energy spread of 1.5 keV below 150 keV, of 1 keV above 150 keV. Measurements up to 400 keV on an enriched Cr-54 sample with an energy spread of 2 keV.

Müller, Rohr /8/ from Karlsruhe in 1969

These were measurements on an enriched Cr-53-sample in the energy range 20 - 250 keV with a time resolution between 0.2 and 0.5 nsec/m and another Karlsruhe measurement by Beer et al. /25/ in 1970 from which only preliminary results are available up to now.

These were transmission measurements on enriched Cr-50 and Cr-52 samples with a time resolution of about 0.4 nsec/m covering the energy range from 10 keV to 300 keV.

Stieglitz, Hockenbury, Block /9/ from RPI in the years 1969-1970

This group has made very extensive measurements on all the stable Cr-isotopes contained in natural chromium. These transmission measurements were performed in the energy range 0.1 - 400 keV with a resolution of 0.6 nsec/m, i.e. an energy spread of 500 eV at 100 keV and of 3 keV at 400 keV.

This RPI-group is the only group which has up to now performed high-resolution capture measurements on all the stable isotopes Cr-50, 52, 53, 54 in the energy range 0.1 - 200 keV.

The RPI-experiment shows the ideal case for a measurement on the structural materials namely combination of transmission and capture measurements. This group found out that the resonance structure observed in the capture measurements is significantly different from that observed in the transmission measurements. The capture measurements emphasize the narrow probably p-wave resonances and the s-wave resonances appear only as wide, relatively flat "bumps" in the data. On the other hand the transmission measurements predominantly show the wide s-wave resonances. Very few of the narrow resonances are seen in transmission. Therefore, radiative capture widths could be assigned by the RPI-group only to very few s-wave resonances which appear in the transmission as well as in the capture measurements. For the narrow higher l-wave resonances only the quantity $g \cdot \frac{\Gamma_n \cdot \Gamma_\gamma}{\Gamma}$ is given by the authors, which is the capture area corrected for resonance self-shielding and multiple scattering. Because of the poorer instrumental resolution at higher energies the resonance parameter analysis for Cr-53 was limited to below about 100 keV whereas for the even Cr-isotopes fits could be carried out to over 300 keV. A comparison of the different sets of resonance parameters is given in the Tables Ia) - d). For Cr-50 (Table Ia) in the RPI measurements 17 s-wave resonances were observed in the transmission measurements.

No evidence of the 43 keV resonance found by Bilpuch et al. was seen in these measurements and also in the Karlsruhe measurements of Beer et al. Instead of this, previously undetected s-wave resonances were observed for the first time by the RPI-group at 55.3, 65.1 and 171 keV. These were confirmed by the preliminary Karlsruhe results of Beer et al. /25/.

Between the results of the two groups below 100 keV excellent agreement has to be noticed in the resonance positions as well as in the neutron widths. Above 100 keV some more smaller resonances were observed in the Karlsruhe measurements which were not detected by the RPI-group probably because of their worse energy resolution. Above 100 keV the resonance energies found by Stieglitz et al. are always higher than those found by Beer et al. and the differences between them become larger with increasing energy. The two resonances at 112/113 and 116/115 keV were assigned to be s-wave by Beer et al. in contrary to Farrell. The agreement between Farrell and the Karlsruhe-results is not so good. There are for some resonances differences in the neutron widths of the order of 50%. The resonances at 307 keV and 327.7 keV reported by Farrell were not observed in the RPI-measurements. This may be due to inadequate instrumental resolution. The four s-wave resonances up to 55.3 keV were equally observed in the capture measurements and so radiation widths could be determined. The only value for the radiative capture width published before the RPI measurements was for the first s-wave resonance in Cr-50 and was reported by Coté to be 2.9 eV. It is in good agreement with the RPI-value. With higher energy above about 200 keV the number of resonances resolved by the RPI-measurements becomes smaller than that of the recent Duke measurements by Farrell due to their better resolution. Farrell has measured up to 600 keV and assigned neutron widths to the s-wave resonances. The narrow resonances observed in the capture measurements have extremely small neutron widths and were therefore and because of the lack of resonance-potential interference assigned by Stieglitz et al. to be very probably p-wave resonances.

It is, however, possible that some of the weaker resonances are d -wave resonances. This is valid for all Cr-isotopes.

Concerning Cr-52 (Table Ib) in the energy range 150 eV - 270 eV there is more structure in the resonance cross section than observed by the RPI-group. This is shown by the measurements of Bowman et al. and Beer et al. who attributed this structure mainly to higher l-wave resonances. The results of the s-wave resonance parameters of the Duke, Karlsruhe and the RPI group agree, however, fairly. There are some differences of the order of 1 - 2 % in the resonance energies given by the RPI and the Duke group. The agreement between the RPI and the Karlsruhe-results is quite good for the strong s-wave resonances. For the four p-wave resonances to which by both groups $g \cdot \Gamma_n$ -values were assigned differences are encountered except for the 132 keV resonance. This resonance was also measured by Bowman et al. and his results, too, agree well with the RPI- and Karlsruhe-results. The agreement between the other Duke results and the Karlsruhe results is in general good in the range where both groups have measured i.e. above 100 keV. The resonance observed by Bowman et al. at 119 keV seems to be according to the Karlsruhe measurements a superposition of the s-wave resonances at 118 keV and at about 121 keV. The same is valid for the resonances observed at 138 keV by Bowman and at 141.4 keV by Stieglitz. Between Stieglitz et al. and/or Bowman et al. on one side and Beer et al. on the other side there are some differences in the assignment of resonances to higher l (>0) wave neutrons.

The RPI-group has only measured up to 300 keV, Bowman from the Duke-group up to more than 600 keV. More recent measurements do not exist in this range.

Concerning Cr-53 (Table Ic) in the energy range between 95 keV and 200 keV much more resonances were observed by the Karlsruhe group:

20 resonances in comparison to the 3 resonances observed by the RPI-group since the former group had a better energy resolution. Below 100 keV good agreement is observed between the two parameter sets not only in the neutron widths but also in the spin assignments. No evidence of the 3.6 keV and the 10.5 keV resonances observed by the Oak Ridge-group by Good et al. was found in the RPI-measurements.

Concerning Cr-54 (Table Id) no evidence of the 26.5 keV resonance reported by Bilpuch et al. was seen in the RPI-measurements. The radiation width could only be determined for one s-wave resonance in Cr-54. A number of smaller resonances above 120 keV reported by Farrell et al. was not observed in the RPI-measurements probably due to inadequate instrumental resolution.

I would like to summarize the present status of resonance information for the chromium isotopes.

For Cr-50, Cr-54 resonance information is now available also above 100 keV.
For Cr-53 much more resonance information exists than in 1966, parameters are known up to about 300 keV.

Some capture widths are also known now, but except for Cr-52 only below 100 keV. For Cr-54 the information about radiation widths is still very poor, only one Γ_γ-value is known but for six resonances capture areas were determined.

Concerning the cross sections in the resonance region it is immediately evident that the total cross section is well known from all these transmission measurements mentioned in the discussion of the resonance parameters. For Cr-50 one may rely on the RPI- and Farrell-results, for Cr-52 on the RPI- and Bowman-results, for Cr-53 on the RPI- and Karlsruhe-results and for Cr-54 on the RPI- and Farrell-results. Below some keV, the energy of the lowest resonance, there exist the measurements of

Melkonian et al. /1/ in the range 0.01 - 170 eV and of Coté et al. in the region 1.3 - 3.0 keV. Both authors were already mentioned in the discussion on resonance parameters. With regard to the radiative capture cross section the situation is not so good. At thermal energy a number of measurements exist and the capture cross section is there well-known. In the eV-range up to 25 keV till 1964 no measurements existed. In 1964 the Russian lead pile measurements of Kapchigashev and Popov /15/ have become available, starting at 30 eV. Below 600 eV the data show already a clear $1/v$ dependence of σ_γ and therefore it is justified to extrapolate σ_γ below 30 eV down to thermal energies. Above 25 keV point wise given cross section values are available from four earlier measurements of

Belanova /11/ 1958/60 at 25 keV, 220, 830 keV
Gibbons et al. /12/ 1961 at 30 keV, 65 keV
Diven et al. /13/ 1960 between 175 keV and 1 MeV
Staviskii, Shapar /14/ 1962 between 35 keV and 1 MeV

Between the results of Gibbons, Diven and Staviskii, Shapar is good agreement, whereas the results of Belanova are about one order of magnitude higher. No reason is known for this discrepancy. Below 50 keV the lead pile data of Kapchigashev et al. are rather low compared in particular to the Gibbon's value at 30 keV. In the last years two sets of capture data on chromium have been published. The first was by Spitz et al. /10/. These were ratio measurements on natural chromium relative to the capture cross section of indium in the energy range 8 - 120 keV. Spitz' results are systematically higher than all other measurements; below 20 keV by about 50%, around 30 keV by a factor of 5. These higher capture cross section data are confirmed by the RPI-measurements of Stieglitz et al. /9/. They have derived from their capture yield measurements interval averaged capture cross sections for natural chromium in the range 10 keV to 200 keV (10 keV-intervals up to 100 keV).

Their average values are higher than the other experimental results except those of Spitz et al. by a factor 2 till 5. Only in the interval 150 - 200 keV their average σ_γ-value is lower than the measurements there. The discrepancies are not so high in comparison with the already relative high Belanova-results.

Resonance neutron nuclear data for iron

The first systematic study of Fe-resonances was again performed by Hibdon /2/ in 1957 with samples of natural Fe and also samples enriched in Fe-54 and Fe-56. It covered the range from 1 keV to 410 keV. Still more extensive measurements were made by the group from Duke University /5/. One of them, Seeth made a careful (area) analysis of the 28.3 keV resonance in Fe-56 but he obtained for the neutron scattering width nearly twice the value of Hibdon (see Table II b). The Duke measurements on natural iron covered the energy range 1 keV - 215 keV, on a sample enriched in Fe-54 the range from 4 to 135 keV. The energy resolution of this transmission measurement was worse than in Hibdon's experiment (Hibdon ΔE: 300 eV - 700 eV; Duke group ΔE: 1 keV - 5 keV). For a comparison of these two first resonance measurements on the Fe-56-isotope we need only to consider Table II b). There is not only a strong discrepancy for the lowest resonance found by Hibdon and the Duke group of Bilpuch et al. at about 28/29 keV, but also for all other resonances detected by both groups except that at 83.5 keV. There is no systematic trend in this discrepancy: most neutron widths of Hibdon are much lower than those of the Duke group but some of them are also higher. No reason is known for the strong discrepancies. Also a shift in the resonance energies is observed between both measurements. Bowman et al. /6/ from the Duke University group extended in 1962 the resonance measurements on Fe-54 up to 500 keV starting at 95 keV and on Fe-56 up to more than 600 keV starting at 185 keV.

As in the case of chromium he had a better energy resolution than the former Duke-experiment but a still worse energy resolution than Hibdon. A comparison of the results of Bowman et al. and Hibdon in the table on Fe-56 resonance parameters shows that the resonance positions are in very good agreement but that the scattering widths are again discrepant by a factor of 1.5 up to 3. In 1963 Hibdon has remeasured and reanalyzed the total cross section in the neighbourhood of the 131 keV resonance in Fe-56 very carefully. He has come to nearly the same value of the neutron width as the Duke group. It seems that something in his former measurements or analysis has not been correct. Below the first resonance observed in Fe-56 by the Duke group and also by Hibdon a resonance at 1.2 keV was detected in capture measurements of Isakov et al. /16/ with the slowing-down-time-spectrometer. This resonance is extremely small in comparison to all other iron-resonances and its radiation width is much larger than its scattering width. The most comprehensive studies on this resonance were done by Moore et al. /17/ in 1963. In the years 1964 till 1971 a number of resonance measurements on natural iron and iron isotopes were reported, among them more transmission than capture measurements. The following groups have to be mentioned in this context:

Moxon /18/ from Harwell performed in 1965 capture measurements in the energy range 1 to 50 keV. He deduced resonance parameters for the three Fe-isotopes Fe-54, Fe-56, Fe-57.

Good et al. /4/ from Oak Ridge made in 1965 transmission measurements below 50 keV on a sample enriched in Fe-57. The energy resolution was better than 2%.

Macklin et al. /19/ from Oak Ridge performed capture and transmission measurements up to 80 keV on samples enriched in Fe-56 and in Fe-57. The time resolution of his measurements was lying between 3 and 10 nsec/m. As in Moxon's capture studies also in Macklin's capture measurements several small resonances were de-

tected which could not be resolved in transmission measurements. This is true of the resonances at 22 and 36 keV in Fe-56, at 17 and 20.5 keV in Fe-57.

Rohr, Friedland, Nebe /20/ from Karlsruhe performed with an overall resolution of 0.39 nsec/m total neutron cross section measurements on natural Fe and analyzed them. Resonance parameters were obtained for Fe-56 in the region 70 keV - 250 keV.

Rohr, Müller /21/ made in 1963 transmission measurements on enriched Fe-57 samples with a time resolution of 0.4 nsec/m. This resolution was according to the authors not sufficient to allow a resonance parameter determination above 200 keV. They have analyzed their results for the elastic and inelastic scattering half widths and the resonance spins in the region 20 keV - 200 keV.

Ernst et al. /22/ from Karlsruhe investigated iron resonances by neutron capture measurements on enriched Fe-56 samples with a time resolution of better than 2 nsec/m. Preliminary results from the analysis of their data have just recently become available.

Beer et al. /26/ performed in 1970 transmission measurements on Fe-54 in the energy range 10 keV up to 300 keV with an energy resolution of about 0.4 nsec/m. The data have been analyzed just recently and the preliminary results are given in Table II a).

Garg et al. /23/ performed in 1964 transmission measurements on natural iron with a time resolution of 0.5 nsec/m. The energy range between 200 eV and a few MeV was covered. In 1971 up to 200 keV a detailed R-matrix multilevel analysis of the data was done and the results of it are given in the Tables II a) - II d) on resonance parameters of the Fe-isotopes.

Hockenbury et al. /24/ from Oak Ridge made a very comprehensive capture measurement on natural Fe and for the isotopic assigment on samples enriched Fe-54, Fe-56, Fe-57, Fe-58. The highest resolution reached in this measurement was 1.3 nsec/m between 25 and 200 keV.

Resonances could be resolved up to 70 keV. Much more resonances were observed in these capture measurements than in earlier transmission measurements, up to 130 keV 50 resonances in comparison to 15 resonances detected till 1966 in transmission measurements. For the resonances for which the neutron widths were known from σ_T-measurements and for which $\Gamma_n \gg \Gamma_\gamma$, the radiation widths were determined by Hockenbury et al. For the narrower resonances, mostly assigned to p-wave neutrons by Hockenbury et al., only in the cases where $\Gamma_n \ll \Gamma_\gamma$ a value of $g \cdot \Gamma_n$ could be determined by the authors from the area under the capture resonance. For the other resonances $g \frac{\Gamma_n \cdot \Gamma_\gamma}{\Gamma}$ was obtained from the resonance capture area by applying sample self-shielding and multiple scattering corrections.

Above 250/300 keV only Bowman et al. have analyzed their measured data and also Hibdon for some isotopes. Since these data are listed in BNL 325 (1966) (2^{nd} edition Suppl. 2) and since they are not used here for comparison with more recent measurements they are not tabulated in the tables II a) and b).

Concerning Fe-54 (Table IIa) below 100 keV good agreement is observed between all available results. Above 100 keV there are differences encountered not in the resonance energies found by the different experimental groups but in the neutron widths assigned by them. The neutron width determined by Garg et al. for the resonance at 71.8 keV seems too high compared with the other results available. The differences in the neutron width of the resonances in the range 100 keV - 130 keV can also not be explained. Two resonances were observed in this range by Bilpuch et al. and Garg et al. whose neutron widths differ by more than a factor 2. Bowman et al. and Beer et al. have detected only one resonance in this range at about 130 keV, the other resonance at about 102 keV was not observed by them.

Their neutron widths for the 130 keV-resonance differ by a factor of nearly 2.5. At higher energies further discrepancies in the neutron widths assigned by Bowman et al. and by Beer et al. are encountered, e.g. around 173 keV, around 230 keV and 245 keV.

Concerning Fe-56 (Table II b) much more resonances were detected in the capture measurement by Hockenbury et al. than previously known. The resonance energies of Fe-56 found by Hockenbury et al. are in very good agreement with those found by Ernst et al. with almost the same energy resolution (Ernst: 2 nsec/m, Hockenbury: 1.3nsec/m). The capture areas determined by them agree fairly with each other, differences of about 30% are encountered. The neutron widths obtained by the different experimentalists agree in general well. Strong discrepancies are only encountered

- for the resonance at about 122 keV between the Γ_n-value given by Garg et al. and the corresponding value obtained by the other groups. Since the difference is just one order of magnitude and since the parameters of the other resonances determined by Garg et al. are in good agreement with other reported values, it cannot be excluded that there is a writing error in the quoted number for Γ_n .

- and as well known from the former discussion for the majority of the Fe-56 resonances found by Hibdon between his results for the neutron widths and the results of the other investigators.

Concerning Fe-57 (Table II c) a comparison of the resonance parameters for the first two resonances in Fe-57 of about 4 and 6 keV shows that the available values are in good agreement apart from the Γ_n-value obtained by Garg for the 6.28 keV resonance. No reason is known for this discrepancy. Above 10 keV two kinds of comparison can be made:

1. for the resonances at about 12 keV and about 17 keV between the results of Moxon, Macklin and Hockenbury. The values of

the capture areas obtained by Moxon and by Macklin for the two resonances agree within their mutual uncertainties, but the results of Hockenbury lie outside the assigned error bars.

2. for the resonances above 25 keV between the neutron widths of Good et al. and those of Rohr et al. Here good agreement is observed. Above 50 keV the only available data on resonance energies and neutron widths for Fe-57 are coming from Rohr et al. According to Rohr et al. in the energy range 120 - 156 keV also another parameter set may give an adequate description of the cross section behaviour since a large number of resonances is superimposed.

For Fe-58 (Table II d) only one resonance measurement was carried out, that by Hockenbury et al. From this experiment resonance energies are known up to 10 keV and for the first two resonances capture areas were determined.

The resonance information available for the Fe-isotopes is summarized by the following facts: The available information about the neutron capture in Fe-resonances has increased in the last years but it is still not sufficient. Below 50 keV for Fe-54, 56, 57 $g\frac{\Gamma_n \Gamma_\gamma}{\Gamma}$ -values or even some Γ_γ-values are known, but below 50 keV means for example that only three resonances in Fe-54 are situated there. The neutron widths are in general well-known for the s-wave resonances in the stable iron-isotopes except for Fe-58. For the higher l-wave resonances, however, spin assignments and consequently accurate values for the neutron widths are lacking.

For Fe-58 the available resonance information is very scarce. Concerning the total cross section measurements in the resonance region the measurements of Hibdon on natural iron were carried out with the best energy resolution in comparison with other earlier measurements.

The measurements by Bilpuch et al. 1961, Bowman et al. 1962, Good et al. 1965, Macklin et al. 1964 had a worse resolution. The best resolution in recent transmission measurements of 0.5 nsec/m was obtained by Garg et al. /22/. He covered also a large energy range from 200 eV to some MeV. The Karlsruhe group /20, 21, 26/ had an equally good resolution but the measurements were not performed on all stable Fe-isotopes and the measurements on natural Fe started at an energy of 10 keV.

As far as the capture cross section is concerned as in the case of chromium, its thermal value is well-known. In the range from epithermal up to 1 MeV we have the same rather old measurement series as for chromium, namely that of

Belanova 1958/60 /11/ at 25, 220, 830 keV
Gibbons et al. 1961 /12/ at 30, 65 keV
Diven et al. 1960 /13/ between 175 keV - 1 MeV
Staviskii, Shapar 1962 /14/ between 36 keV - 1 MeV

In addition resonance capture cross section measurements exist from

Isakov et al. /16/ 1961, 0.1 eV - 50 keV
Macklin et al. /19/ 1964, 10 keV - 60 keV only Fe-56, Fe-57
1967, 125, 150, 182 keV
Moxon, Rae /27/ 1963-65, 1 keV - 100 keV
Malyshev et al. /28/ 1964, 30 keV - 1.4 MeV
Mitzel, Plendl /29/ 1964, 10 keV - 60 keV

and also more recent measurements of

Chou /30/ 1970 1 eV - 50 keV
Hockenbury et al. /24/ 1969 100 eV - 200 keV
Ernst et al. /22/ 1970 7 - 200 keV only Fe-56

The Mitzel et al. and Isakov et al. measurements are measurements using a slowing-down-time-spectrometer. But in spite of

the fact that they used the same method, discrepancies were encountered in the results of both measurements and some time has passed until they became solved. The first discrepancy was given by an energy shift of the two $\sigma_\gamma(E)$-curves by about 1 - 3 keV at energies above 2 keV and the second discrepancy by the different peak heights in the capture cross section from both experiments. This latter difference was clarified and is due to differences in the amount of impurity admixtures in the iron samples used in both measurements. The first discrepancy could not be solved but it was the Mitzel et al. measurement at Karlsruhe in which the energy scale was wrong. This was found out by Chou /30/ who repeated the measurement in Karlsruhe with the same slowing-down-time-spectrometer as used by Mitzel et al. Chou could also confirm the correctness of the reason responsible for the second discrepancy, i.e. with his very pure iron samples he did not observe any resonance structure in iron below 1.2 keV, the lowest resonance in Fe-56. Thus the differences between the measurements with a slowing-down-time-spectrometer are well understood. The largest discrepancies in the resonance capture cross section of iron, however, exist in the range 1 keV - 100 keV between the lead pile measurements on one side and the linear accelerator measurements made at Harwell and Oak Ridge on the other side. On the average they differ by a factor 2 - 3. Among themselves the Harwell- (Moxon, Rae) and Oak Ridge- (Macklin) results are in good agreement except for the Fe-56 resonance at 28 keV. The large difference there is probably due to the fact that the Harwell measurements were not corrected for multiple scattering. The 28 keV resonance is the lowest strong scattering resonance in natural iron, so that multiple scattering corrections would be particularly necessary there. The other differences between the Harwell- and Oak Ridge-values are smaller and due to differences in the isotopic composition of the samples. The discrepancies with respect to the lead pile measurements are so far unexplained.

Also the recent lead pile measurements of Chou give results which agree within 10% with the two other lead pile measurements but are systematically lower than the results using other experimental methods.

Resonance neutron nuclear data for Nickel

Nickel shows a similar level structure as iron: large s-wave resonances superimposed by many narrow resonances. The analysis of Nickel resonance cross section data is complicated by a closer level spacing than iron.

Before 1958 no resonance parameter analysis on Ni-resonance cross sections was performed by any laboratory, only transmission measurements in which broad resonances were observed since these measurements were done on natural nickel and thus contained an overlapping of the resonance structure of the different stable isotopes. Also the energy resolution was in most cases very bad. The first extensive experimental end analysis work on Ni-resonances became available by the group from Duke University /5/. They measured the total cross section on Ni-samples enriched in the main isotopes Ni-58 and Ni-60 in the energy range from 3 to 230 keV. The energy resolution in their measurements varied between 1 keV and 5 keV. No resonance could be attributed by the authors with any certainty to higher l-wave neutrons. In order to obtain a satisfactory fit to their measured σ_T-data in the lower keV-range they introduced a resonance at negative energy of - 28.5 keV with the reduced neutron width of 70 eV. In 1964 Garg et al. /23/ performed transmission measurements on natural Ni-samples in the range between 200 eV to about 340 keV. As we know already from their measurements on iron they had a good resolution of 0.5 nsec/m. Garg et al. made in 1964 no parameter analysis. They extracted only the resonance energies and the isotopic assignment of the resonances. These results agree in general well with the corresponding values of the Duke group (see Table III a) - e))

Only below 30 keV there seems to be an energy shift between both measurement series. The resonance energies found by the Duke group are about 1 to 2 keV higher than those found by Garg. Up to 1966 no new measurements on Ni-resonances became available and the situation was as follows:

For Ni-62 only one resonance was known, for Ni-64 and Ni-61 no resonance parameters were known and even no resonances assigned. For the most abundant isotopes Ni-58 and Ni-60 no resonance parameters were known above about 200 keV. No radiation width for any of the Ni-resonances had been measured. No higher l-wave resonances were known in contrary to iron and chromium.

In comparison to the situation at that time for iron- and chromium-resonances the resonance information for the nickel isotopes was extremely bad. This explains the large number of resonance cross section measurements performed in the then following years. All the authors of these recent measurements are already known to us from their resonance measurements on Fe- or Cr-isotopes.

Transmission measurements were performed by the following groups:

Farrell et al. from Duke University in 1966 /7/ on Ni-58, Ni-60, Ni-62, Ni-64 in the range 100 keV - 600 keV using an energy resolution of 1 keV.

Good et al. from Oak Ridge in 1965 /4/ on Ni-61 up to 50 keV with an energy resolution better than 2%.

Cho , Fröhner et al. from Karlsruhe in 1970 /32/ on Ni-58, Ni-60, Ni-61 in the energy range 10 - 250 keV with a time resolution between 0.2 - 0.5 nsec/m.

Beer et al. from Karlsruhe in 1970 /25/ on Ni-62, Ni-64 in the region 10 keV - 300 keV with a time resolution of 0.4 nsec/m. Preliminary results are available.

Stieglitz et al. from RPI in 1969/70 /9/ on Ni-60 between 0.1 - 400 keV with a resolution of 0.6 nsec/m.

Garg et al. /23/ performed in 1971 a R-matrix multilevel analysis of their data measured in 1964, from which they had originally only extracted the resonance energies.

Capture measurements were carried out by the following authors:

Hockenbury et al. /24/ from Oak Ridge in 1969 on Ni-58, Ni-60, Ni-61, Ni-62, Ni-64 in the energy range between 100 eV and 200 keV with an energy resolution of 1.3 nsec/m at best.

Ernst et al. /22/ from Karlsruhe in 1970 on Ni-58, Ni-60, Ni-61 in the region between 7 and 200 keV with a time resolution better than 2 nsec/m.

Stieglitz et al. /9/ from RPI in 1969/70 on Ni-60 between 0.1 and 200 keV.

In the Tables III a) - e) a survey is given on the resonance parameters extracted from all these measurements. Hockenbury et al. determined radiation widths only for those resonances whose neutron widths are well known. For most of the other resonances the resonance capture areas $g\frac{\Gamma_n \Gamma_\gamma}{\Gamma}$ corrected for multiple scattering effects and resonance self-shielding were given. Stieglitz et al. have followed the same procedure:

for the resonances observed in their transmission as well as in their capture measurements they have given radiative capture widths, for the other resonances only the corrected capture areas. As in the case of iron the small resonances were assigned to p-wave neutrons. It may be, however, that at least some of them have to be attributed to higher l-wave neutrons. The resonance parameters given in the tables under references Fröhner /32/ were obtained by an analysis of transmission measurements by Fröhner et al. /32/ and of capture measurements by Ernst et al. /22/. These results are preliminary.

Concerning Ni-58 (Table III a) resonances were resolved up to 130 keV by Hockenbury and Fröhner et al. They had an equally good energy resolution and therefore the agreement in resonance positions and assigned parameters is very good. But also the resonance parameters found for the s-wave resonances in this range by Garg et al. and by Bilpuch et al. agree well with each other.

Above 130 keV the resolution of the Fröhner- and Hockenbury-measurements was not high enough to separate different levels. Above this energy the results of Farrell et al. play a predominant role. In addition to them exist only for the large s-wave resonances parameters from Bilpuch et al. and Garg et al. For the resonances at about 157 keV and between 136 - 140 keV some differences are observed in the resonance positions and also the neutron widths. The value given by Bilpuch et al. for the neutron width of the resonance at about 157 keV seems to be too low compared with the two values reported by Farrell and by Garg. From the neutron widths given in the energy range 136 - 140 keV it seems as if the resonances found by Farrell at 138 keV was observed by Garg at 140.5 keV and the resonance assigned by Farrell to be at 136 keV was detected at 137.5 keV by Garg. If this is true, then there is a discrepancy encountered between the neutron width reported by Farrell and by Garg for this latter resonance. The high value in the neutron width given by Bilpuch for the resonance at

138.5 keV can be understood, since he has detected instead of the - according to Farrel and Bilpuch - two resonances of almost equal width only one larger resonance. Radiative capture widths are known for Ni-58 from most recent analysis work for the s-wave resonances up to 130 keV.

Concerning Ni-60 (Table III b) below 100 keV the most important experimental and analysis work was done by Stieglitz et al., Hockenbury et al. and Fröhner, Ernst et al. Excellent agreement is observed in the resonance energies of the three parameter sets although in some cases Hockenbury et al. have missed a smaller resonance detected by Fröhner and Stieglitz. The resonance parameters of these three sets are also in good agreement with each other. The results of Bilpuch et al. and of Garg et al. for s-wave resonances are equally in accordance with the results of the three main measurement series. Above 120 keV the resonances could not be resolved in the measurements of Fröhner et al. and Hockenbury et al. In this energy range the results of Farrel et al. and also of Stieglitz et al. are available. The parameter sets reported by both authors are in good agreement with each other and as far as the s-wave resonances are concerned in general also with results of Bilpuch et al. and of Garg et al. There are three cases in which the discrepancies in the neutron width values are considerable, namely for the resonances at about 108 keV and at about 161 keV Garg et al. have obtained from their analysis a value for the neutron width which seems too high (factor 2 and 3 resp.) in comparison with the other reported values and for the resonance at about 197 keV Bilpuch et al. have obtained a neutron width higher by a factor of about 2 compared to the three other results for this resonance.

Radiation widths are known for Ni-60 resonances from the most recent measurements only for the s-wave resonances up to about 160 keV.

For Ni-61 (Table III c) three parameter sets exist: that of Good et al., of Hockenbury et al. and of Fröhner, Ernst et al. Good et al. have in general only detected s-wave resonances in their measurements and analyzed. The resonance positions given by the just mentioned three groups are in good agreement, although some resonances around 26 keV and 13 keV were very probably missed in the measurements of Hockenbury et al. and although only the positions of s-wave resonances were given by Good et al. Spin assignments to the resonances were only made by the Fröhner group. A comparison of the resonance parameters is not so easily done since the three groups have reported different quantities. Using the spin assignments of Fröhner et al. one sees that the capture areas given by Hockenbury for the resonances at 7.12 keV and at 8.71 keV are consistent with the parameters given by Fröhner et al. Below 7 keV no comparison is possible since Fröhner has not measured there. The capture areas reported by Hockenbury at 24.8 keV and 27.6 keV cannot be compared with results of Fröhner since the latter has detected around these energies more than one resonance. The results of Good et al. are for most of the analyzed resonances not in concordance with the Γ_n-values obtained by Fröhner et al. at least if one relies on the spin assignments as given by Fröhner et al.

Above 70 keV no resonance parameters exist for Ni-61. Radiation widths are known for most s-wave resonances up to about 40 keV.

For Ni-62 (Table III d) only two comprehensive measurement series were performed: that of Farrell et al. and of Beer et al., where Beer et al. have had an energy limit of 300 keV for separating the different levels. Between the resonance energies and also the neutron widths determined by both groups is excellent agreement.

Some resonances, however, are attributed by Beer et al. to s-wave neutrons, whereas by Farrell to higher l-wave neutrons. In addition to these two measurement series there are up to about 150 keV some results of Garg et al. which are in concordance with the results of Beer and Farrell.

Radiative capture widths are only known for the resonance at 4.6 keV.

Concerning Ni-64 (Table III e) the main investigators of the resonance properties are as in the case of Ni-62 Beer et al. and Farrell et al., Hockenbury et al. have measured resonance energies up to about 80 keV and determined a capture area for the first resonance. The energies and parameters assigned to the resonances of Ni-64 by Beer et al. and Farrell et al. are in good agreement apart from the neutron width for the resonance at about 163 keV which differs by a factor of about 2. In the range between 200 keV and 230 keV Beer et al. have detected three additional resonances compared with those of Farrell. Also the assignment of the resonances to higher l-wave neutrons is in concordance in the two sets of Farrell and Beer. Above 290 keV up to about 600 keV the results of Farrell are the only ones available. No capture widths are known for Ni-64, only the capture area for the first resonance.

Summarizing the gaps in the resonance information for the stable Ni-isotopes one can say that the information on higher l-wave resonances in particular spin assignments is not yet satisfactory for all Ni-isotopes.
This means that the resonance cross sections can be well described by resonance parameters in the neighbourhood of strong s-wave resonances but not in the valleys between them with all the superimposed higher l-wave resonances. Concerning the radiation widths no information is available for Ni-64, for Ni-58 and Ni-60 above about 100 keV, for Ni-61 above about 40 keV and for Ni-62 only one capture width is known. For Ni-61 no resonances, even no s-wave resonances, are known above about 80 keV.

Concerning the total cross section in the resonance region we have already mentioned all the transmission measurements per-

formed on Ni-isotopes. The whole resonance energy range up to 600 keV is covered by them

Ni-58	3 - 330 keV Bilpuch et al.,100 keV - 600 keV Farrell et al., 10 - 250 keV Fröhner et al.
Ni-60	3 - 330 keV Bilpuch et al., 100 keV - 600 keV Farrell et al., 10 - 250 keV Fröhner et al., 100 eV - 400 keV Stieglitz et al.
Ni-61	10 - 250 keV Fröhner et al., 1 keV - 50 keV Good et al.
Ni-62 Ni-64	10 keV - 300 keV Beer et al., 100 keV - 600 keV Farrell et al.
natural Ni	200 eV - 340 keV Garg et al.

So the total cross section is well determined in the resonance range except perhaps for Ni-61 in the upper region. One has only to add together the contributions from the several isotopes to the total cross section at one and the same energy.

Concerning the resonance capture cross section between thermal energies and 25 keV no σ_γ-values were known before 1960. Between 25 keV and 200 keV only some scattering experimental results existed coming essentially from the same authors as the first capture results for iron and chromium, namely from

Belanova	1958/60	/11/	at 25 keV, 220 keV, 830 keV
Gibbons et al.	1961	/12/	at 30, 65 keV
Diven et al.	1960	/13/	between 175 keV - 1 MeV
Staviskii, Shapar	1962	/14/	" 36 keV - 1 MeV

In addition resonance capture cross section measurements on Nickel were carried out by

Isakov et al.	1961	/24/	0.1 eV - 50 keV
Macklin et al.	1963	/33,19/	30, 65 keV (same values as given earlier by Gibbons)
	1967		125, 150, 182 keV
Bergquist, Starfelt	1961	/36/	125 keV
	1963		15, 30, 50, 65 keV
Kapchigashev, Popov	1964	/35/	30 eV - 30 keV

Kapchigashev et al. investigated more thouroughly than Isakov et al. the radiative neutrons capture in natural nickel by using also a slowing-down-time-spectrometer. They applied on their results the important correction for multiple scattering before capture. Kapchigashev et al. found from 30 eV up to 1.5 keV a clear $1/v$ dependence of σ_γ so that below 1 keV the capture cross section is well-known. Above 3 keV the results of Isakov et al. are much higher than the results of Kapchigashev et al. due to the multiple scattering correction. The last value of Kapchigashev at about 32 keV agrees well with the result of Gibbons et al. at 30 keV but both are by a factor of 2 lower than Staviskii's result at 35 keV. There is even a discrepancy between the Staviskii value at 175 and the Diven value at this energy in spite of the fact that the Staviskii results were normalized to Diven's 400 keV-value. At the other energies the agreement between Diven and Staviskii is however good on the average. As for iron and chromium Belanova's results lie extremely high above all other results. This is only partly due to the fact that these results were not corrected for multiple scattering effects. Also for the experimental results of Bergquist, Starfelt it is not clear from their report whether this kind of correction has been applied or not. In the last years as we know already from the discussion of resonance parameters new capture measurements became available, carried out by the following authors:

Hockenbury et al.	on Ni-58, 60, 61, 62, 64 up to 200 keV
Stieglitz et al.	on Ni-60 up to 200 keV
Ernst et al.	on Ni-58, 60, 61 up to 200 keV and
Spitz et al. /10/	on natural nickel from 8 keV up to 120 keV measured relative to σ_γ(In)

The results of the Spitz et al. measurements are much higher (by a factor of about 2 above 15 keV and below 15 keV by more than that) than the experimental results of Kapchigashev et al. and of Gibbons et al. in the measured range 8 - 120 keV. The data of Staviskii et al. are in good agreement with those of Spitz. The Belanova value at 25 keV is still higher than Spitz' results by 10 - 20%. A comparison of the Hockenbury results is not so easily to perform because of all the isotopical contributions. Stieglitz has only measured on Ni-60 samples.

Some preliminary results of a measurement of the capture yield for several Ni-samples at Harwell confirm the higher cross sections of Spitz et al. as it was stated by Moxon at the Helsinki Conference(CN-26/32).

III. Fast neutron nuclear data for the structural materials: chromium, iron, nickel

Total cross section

For this cross section type high-resolution and very accurate measurements were performed on all the three considered structural materials by Cierjacks et al. /84/ in Karlsruhe. Since the availability of these measurements in 1968 the total cross section can be considered to be well-known. Therefore we will only shortly summarize the available high accuracy measurements performed on the structural materials over a larger energy range. Before 1962 only rather badly resolved and scattered measurements were available.

Elements	References	Year	Energy region	Resolution	$\frac{\Delta\sigma_T}{\sigma_T}$ /%/
Cr	Bratenahl et al. Phys. Rev.110,927	1958	7.05-14.5 MeV	7 MeV: ± 170 keV 14 " : ± 70 keV	± 1
	Foster, Glasgow Phys.Rev.C3 (1971) 576	1963	2.4-15 MeV	2 - 4%	± 1-3
	Cabé et al. Compt.Rend.258, 1478	1964	0.5-1.2 MeV	± 4 keV	± 3
	Manero Anales Real Soc. Espan.Fis.Quim.63A 161	1967	3.2-9.2 MeV	± 30 keV	—

Elements	References	year	Energy region	Resolution	$\frac{\Delta\sigma_T}{\sigma_T}$ [%]
	Cierjacks et al. KFK1000 and Suppl.	1968f.	0.5-32 MeV	(0.045-0.054) nsec/m	$\leq \pm 3$
Fe	Bratenahl et al. Phys.Rev.11o,927	1958	7.05-14.5 MeV	7MeV: $\pm$170 keV 14MeV: $\pm$ 70 keV	± 1
	Foster, Glasgow Phys.Rev.C3(1971) 576	1963	3 - 15 MeV	2 - 4 % of E_n	1 - 3
	Smith et al. ANL-6792 p.29	1963	0.5-1.5 MeV	0.06-0.08 nsec/m	-
	Manero et al. Nucl.Phys.59,583	1964	8.3-14.3 MeV	$\pm$ 30 keV	+ 1.5 - 2
	Cabé et al. Nucl.PhysA102,92	1965	350keV-1.2MeV	$\pm$ 3 keV	± 3
	Albergotti,Ferguson Nucl.Phys.82,652	1966	12.5-14.3MeV	36 - 161keV	± 1
	Ferguson, Albergotti Nucl.Phys. A117,472	1968	1.8-2.6 MeV	1.792MeV: $\pm$2keV 2.365MeV: $\pm$4.6keV	-
	Barnard et al. Nucl.Phys.A118,321	1968	0.3-1.5 MeV	$\approx$ 2 keV	3-5
	Carlson et al. Nucl.Sc.Engng.42(70) 28 and Phys.Rev.158(67) 1142	1969	0.5- 9 MeV	1MeV:0.039nsec/m 9MeV:0.035nsec/m	$\pm$ 2-5 statistical only
	Cierjacks et al. KFK 1000 and Suppl.	1968f.	0.5-32MeV	0.043 nsec/m	$\leq \pm 3$

Element	References	year	Energy region	Resolution	$\frac{\Delta\sigma_T}{\sigma_T}$ / %
Ni	Bratenahl et al. Phys.Rev.110,927	1958	7.05-14.5MeV	7MeV:±170keV 14MeV:± 70keV	± 1
	Foster,Glasgow Phys.Rev.C3(1971) 576	1963	2.4-15 MeV	(2 - 4)%	±(1-3)
	Cabé et al. EANCD(E)-49"L", p.66	1963	0.5-1.2 MeV	± 5 keV	± 3
	CEA-R-3279		3.8-5.2 MeV	±15-20 keV	± 3
	70 Helsinki Conf. Vol.2, 31	1970	0.1-1.2 MeV	± 2keV;±35keV	± 3
	Cierjacks et al. KFK453 and KFK1000 and Suppl.	1968f.	0.5-32 MeV	0.047 nsec/m	≦ ± 3

As one sees immediately from this survey table, for Cr and Ni no other measurement series exist with such a good energy resolution as the measurements of Cierjacks et al. This is also the most extensive measurement series covering the whole range above the resonance region up to 15 MeV, the upper energy limit of fast neutrons in reactors. Concerning Fe the measurements of Carlson et al. were performed with even a slightly better energy resolution (0.035 vs. 0.043 nsec/m). Also the Smith measurements have an energy resolution comparable with that of the Cierjacks experiment. The iron cross sections obtained by Carlson et al. are in good agreement with the Karlsruhe-data of Cierjacks et al., not only with respect to the positions at which structure was observed; but also with regard to the cross section values in the valleys.

The most important absorption reactions on the structural materials are apart from the (n,γ) process in the keV-range the (n, p) - and (n,α) process in the MeV-range. For the main isotopes they are mostly exothermal. These processes and in addition the inelastic scattering will therefore be discussed in particular detail.

Radiative capture cross section

For the capture cross section almost no measurements are available in the range 1 to 10 MeV neither for natural Cr, nor for natural Fe and Ni. For Cr and Fe at least one σ_γ-value of CVelbar et al. /37/ at 14.1MeV exist which can be used to normalize a theoretically calculated curve.
It is, however, not of crucial importance for fast reactors to know the capture cross section of the structural materials in the higher MeV-range more accurately than about 20%, since there $\sigma_\gamma \ll \sigma_p$ and the (n,p) cross sections are in general not better known than to about 15%.

(n,p) - cross section

Chromium

The very small number of experiments performed on the (n,p) cross section of the Cr-isotopes consist of measurements at only one energy point around 14 MeV. There is one exception: Kern et al. /38/ have performed more extensive measurements on Cr-52 covering the range 12.3 - 18.25 MeV. Theoretical model calculations for the (n, p) cross section were performed by a number of authors

by Ringle /39/ on Cr-52 resulting in systematically too high σ_p-values compared with the results of Kern et al.

by Büttner [40] on Cr-50, 52 giving for Cr-52 too lower results than experiments and too higher results for Cr-5o(only experimental values around 14 MeV)

By Eriksson [41] at 2, 5, 10, 15 MeV for Cr-50, 52, 53, 54 resulting in higher values for Cr-50, lower values for Cr-52 compared with experiments, and fitting well the few available experimental data for Cr-53, Cr-54.

The statistical model was used by these authors and the improvements reached in the calculations are due to an improved treatment of the level density. Common to all theoretical calculations is the difficulty of a correct treatment of the Coulomb part in the potential. The uncertainty in the (n, p) cross section of chromium is of the order of 30%. An improvement can only be expected from new measurements in particular for the main isotope Cr-52. [123]

Iron

For the (n, p) cross section of the most abundant Fe-isotope Fe-56 apart from several measurements around 14 MeV and some measurements of the fission spectrum average of σ_p systematic studies of the energy dependence of the (n,p) cross section of Fe-56 were performed by three groups:

Terrell, Holm [42] in 1958 between 3.4 and 8.2 MeV and 12.4 and 17.8 MeV

and more recently

Santry, Butler [43] in 1964 over the whole energy range between the effective threshold of about 4.5 MeV and 20 MeV

Liskien, Paulsen [44] in 1965 between 6 - 8.2 MeV and 12.6 - 19.6 MeV

The three data sets are in good agreement and up to about 13 MeV the (n, p) cross section of Fe-56 is well determined by them. Around 14 MeV, where much more experimental results are available, differences between the several measurement series are encountered in general of the order of 10%, in particular cases the deviations towards higher values amount to about 30% in comparison with the majority of the measurements. Bullock, Moore /45/ and Büttner et al. /40/ calculated σ p(E)-curves for Fe-56 by using the statistical model. The shape of the (n, p) cross section is well reproduced with a slight shift of the maximum to higher energies but quantitatively the calculated curves are both lower in comparison with experiments. The results of Bullock et al. give better agreement with the experimental values than those of Büttner et al. The values obtained by Eriksson from statistical theory agree at 5 MeV well with the experimental data and are at 10 and 15 MeV much higher than most of the measured data.

Apart from Fe-56 the most abundant isotope in natural iron is Fe-54. It is of particular importance for the (n, p) cross section of natural Fe, since the (n, p) reaction on Fe-54 is exothermal and since therefore Fe-54 gives in the lower energy range below about 4 MeV the only contribution to the (n, p) cross section of natural iron.

Systematic measurements for the (n, p) cross section of this isotope exist only in the range between 2 and about 7 MeV. Above this energy no extensive studies were performed, only scattered data points are available between about 14 MeV and 15 MeV. Most of them are in good agreement. The measurement series available in the energy region 2 - 7 MeV are those of

van Loef /46/ from 1961 between 2.6 and 3.6 MeV

Lauber, Malmskog /47/ from 1964 between 2.3 and 3.8 MeV

Carroll, Smith /48/ from 1965 between 3.55 - 6.02 MeV

Salisbury, Chalmers /49/ from 1965 between 2.2 - 6.2 MeV

Above 3.5 MeV these measurements are in good agreement within their mutual uncertainties. Below 3.5 MeV Salisbury's value at 2.23 MeV and van Loef's result at 2.6 MeV are far above the σ_p- curve defined by Lauber's experimental data. This discrepancy is up to now unexplained. If van Loef's and Salisbury's results are correct this would give a much higher contribution of the (n, p) cross section of Fe-54 to the neutron absorption of natural Fe below 2 MeV. The change in the (n,p) cross section would amount to a factor between 2 and 3. On the other side Lauber's measurements are very reliable because of their normalization to the well-known (n,p) scattering cross section. The fission spectrum average of σ_p(Fe-54) gives also no means to decision since the contribution of the energies below 2 MeV is only of the order of the experimental uncertainty of this average.

A theoretical estimate for σ_p(Fe-54) was performed by Büttner et al. /40/ but it gives considerable lower results compared with the experimental data. The σ_p-values calculated by Eriksson /41/ for Fe-54 are well compatible with experimental data. The abundance of the other two stable isotopes in natural iron, Fe-57 and Fe-58 is very small. Only scarce experimental information about their (n, p) cross section exists around 14 MeV. Since the cross section values for Fe-57 are there of the order of magnitude of 100 mb and for Fe-58 of 50 mb, their contributions to the (n,p) cross section of natural Fe can be considered as negligible. /123/

In conclusion one can say:

The (n, p) cross section of natural Fe is not satisfactorily known below about 3.5 MeV due to the discrepancies encountered in the (n, p) cross section of Fe-54 which gives in this range the only contribution from all Fe-isotopes contained in natural Fe.

Furthermore the (n, p) cross section of natural Fe is not well defined in the range between 7 and about 14 MeV because of the lack of experimental results for σ_p (Fe-54) and also because of the discrepancies in the experimental σ_p-data of Fe-56 around 14 MeV.

Nickel

The (n, p) reaction on Ni-58 is exothermal and is the most important among the neutron absorption processes of the stable Ni-isotopes in the MeV-range. Therefore, a large number of measurements was performed on it. We shall only review the most extensive measurements. Among them are those of

Meadows, Whalen	/50/	in 1963 in the energy range 1.04-2.67 MeV
Nakai et al.	/51/	in 1962 in the range 1.84 - 4.82 MeV
Konijn , Lauber	/52/	in 1963 in the range 2.2 - 3.8 MeV
Temperley	/53/	in 1968 in the range 2.2 - 3.8 MeV and 13.7 -14.8 MeV
Barry et al.	/54/	in 1962 in the range 1.625 - 8.33 MeV, 14.8 MeV

Between the results of Meadows et al., Konijn et al., Barry and Temperley good agreement is observed in the overlapping energy regions. Below 3 MeV the agreement with the data of Nakai et al. is equally good, but above this energy differences of more than 20% are encountered between the results of Nakai et al. and the other reported results. Between 5 and 13 MeV no measurements at all are available. In the energy range between 13 and 15 MeV the two most important (good accuracy of 8%, covering larger energy range) measurement series available are that of Glover, Weigold /55/ from 1962 in the range 13.86 - 14.88 MeV
Bowman et al. /56/ from 1966 in the range 12.95 - 19.6 MeV

They are in good agreement with each other but in disagreement with other measurements there, mainly with those of the group of

Chojnacki, Decowski /57, 58/ whose results are much higher (by a factor of about 1.5). They have performed two measurements but the results of the latter /58/ are even higher than those of the earlier ones /57/. Theoretical studies of the (n, p) cross section of Ni-58 were carried out by Eriksson /41/ at 2 MeV where good agreement is observed and at 5 MeV where his value is higher and at 15 MeV where his value is lower than experimental data; by Büttner et al. /40/ using the evaporation model and obtaining results compatible with existing experiments, and by Bullock et al. /59/ on the basis of the statistical model, the results of which are considerable lower than the experimental data.

For Ni-60, the most abundant isotope in natural Ni apart from Ni-58, except several measurements around 14 MeV and of the fission spectrum average of σ_p only measurement series exist from the Geel group of

Liskien, Paulsen	from 1965 /60/ in the range	12.7 - 16.5	MeV
	from 1966 /44/ in the range	6.2 - 8.3	MeV
Paulsen	from 1967 /61/ in the range	5.5 - 6.5	MeV
		8.5 - 12.5	MeV
		17 - 20	MeV

No other measurements studying the energy dependence in the (n,p) cross section of Ni-60 were performed. The (n, p) cross section of Ni-60 is well defined by the Geel measurements above about 5.5 MeV but there is no experimental information between the threshold at about 2 MeV (effective threshold at about 4 MeV) and 5.5 MeV.

Concerning the less abundant Ni-isotopes Ni-61, 62, 64 experimental data are only available for neutron energies around 14 and 15 MeV. Since the measured 14 MeV-values are still smaller than the corresponding σ_p-value for Ni-60 which is much smaller than σ_p (Ni-58) and also because of their small abundance one can neglect the contributions of these isotopes to the (n, p) cross section of natural Ni.

In conclusion on the situation of the (n, p) cross section of natural nickel one can say that this cross section is not well enough defined between about 3.5 MeV and 5.5 MeV due to the complete lack of experimental data for the (n, p) cross section of Ni-60 and also due to the discrepancy in the experimental results for σ_p (Ni-58) of Barry and Nakai. Furthermore there is an uncertainty in the (n, p)-cross section in the region 9 - 13 MeV due to the lack of experimental results for σ_p(Ni-58).

(n,α) cross section

Although the (n,α) process is of less importance than the (n, p) process in structural materials, the neutron absorption by the (n, α) process is considerable higher than by radiative capture. /123/ Furthermore the swelling and high temperature embrittlement of fuel canning materials by He-buildup due to the (n,α) reaction has recently been recognized as a serious safety limitation of the achievable burnup in fast reactors. A short summary of the available experimental information on σ_α is therefore given below.

Chromium

For the chromium isotopes only one σ_α-value was measured and this for Cr-54, the isotope with the lowest abundance in chromium.

Iron

For Fe-56 all the available σ_α-measurements are confined to thermal energies and the results are rather contradictory here (ranging from 0.01 mb to 40 mb). For Fe-54 one systematic measurement of Salisbury, Chalmers /45/ exists between 2.2 - 6.2 MeV and 13.1 MeV and 16.8 MeV.

Between 13 - 15 MeV some other results are available which are compatible with Salisbury's values. Below 4 MeV Salisbury's data show after the decrease from higher energies an increase in the $\sigma_{n\alpha}$-values to a plateau between 2 and 3 MeV. Such a behaviour is not expected from theory and it is very probably due to difficulties in measuring this small cross section of about 5 mb. Because of the smallness of the (n,p)-cross section this deficiency in Salisbury's measurements is however not of importance. Between 6.2 and 13 MeV no measurements are available.

Nickel

Concerning nickel only two experimental values at about 14 MeV exist for Ni-58 and one $\sigma_{n\alpha}$-value measured at 14.8 MeV for Ni-61, 62, 64. In the last years discrepancies have been noted between the small amounts of helium calculated from known or theoretically expected (n,α) cross sections for nickel and the experimental results for helium generated in irradiated high-purity nickel stainless steels /85/. It was found out that these large amounts of helium were generated by the Ni-59 (n,α) Fe-56 reaction with thermal neutronswhere the Ni-59 was built up by neutron capture in Ni-58.

As a conclusion one can keep in mind that the situation about the (n,α) cross section of the structural materials is very bad since even for the main isotopes no experimental data exist and since theoretical calculations are not reliable for the charged particle reactions as we know from the discussion about the (n,p) cross section.

The other reactions under emission of charged particles like (n, d), (n, t), (n, pn), (n, nα) etc. are of less importance for the neutron absorption of the structural materials in fast reactors because of their high threshold energies. Also the (n, 2n) process contributes only very little and we shall therefore only shortly summarize the experimental studies on it.

(n, 2 n)-cross section

For chromium the main contribution to the (n, 2n)- cross section comes up to 13 MeV from Cr-53, since it has the lowest threshold, but no measurements exist for this isotope. For the Fe-isotopes, experimental results are only available for Fe-54. As one knows from nuclear systematics the main contribution to the (n, 2n) cross section of natural Fe comes, however, from Fe-56 at energies above the threshold of the (n, 2n) process in Fe-56 i.e. above 11.4 MeV, below this threshold energy from Fe-57 since this Fe-isotope has the lowest (n, 2n) threshold (at 7.8 MeV).

Concerning the nickel isotopes measurements are only available for Ni-58 and for this isotope over the whole energy range between threshold and 15 MeV. But the threshold of the (n, 2n) process in Ni-58 lies at about 12.5 MeV and above this energy the main contribution to the (n, 2n) reaction in natural Ni comes from Ni-60 as estimates from nuclear systematics show. For a determination of the (n, 2n) cross section of natural nickel the measurements on Ni-58 are therefore of less importance.

Inelastic scattering cross section

The inelastic scattering process gives apart from the elastic scattering process in the higher keV- and the MeV-range the main contribution to the total cross section. Up to a certain energy the inelastic excitation levels can be resolved experimentally. The region below this energy is therefore called the region of discrete levels, whereas the region above this energy is called the continuum range. For determining the cross sections for excitation of the discrete levels by inelastic scattering two alternative experimental methods are in use:

1. Detection of the scattered neutron and registration of the number of inelastic scattering events as a function of the energy of the scattered neutron. Here one has resolution limitation in the energy measurement of the scattered neutron.

2. Detection of the de-excitation gamma rays originating from the nuclear levels excited by inelastic scattering.

The knowledge about the inelastic scattering cross sections depends therefore strongly on the present knowledge about the level schemes and the branching ratios in the γ-decay of the different levels.

Chromium

For natural chromium and the Cr-isotopes rather scarce experimental information on the total inelastic scattering cross section and the inelastic excitation cross sections is available. The most comprehensive investigation was performed by van Patter et al. /62/ covering for Cr-50, 52, 53, 54 the energy range from threshold up to about 3.3 MeV. For Cr-52 an equally extensive measurement was carried out by Broder et al. /63/ up to 4 MeV and for natural chromium by Kiehn et al. /64/. The uncertainty of these measurements lies between 15 and 30%. The experimental information is not sufficient to obtain for all the different levels of the chromium-isotopes a good fit by means of Hauser-Feshbach-calculations. But improvements are to be expected from new measurements of the Studsvik group /75/ in the energy range 2 - 4.5 MeV and of the Oak Ridge group /78, 81/.

Iron

Many measurements were performed on neutron inelastic scattering

excitation cross sections of energy levels in Fe-isotopes but apart from some measurements for Fe-54-levels only for the most abundant isotope Fe-56. In particular most of the experiments are concerned with the 845 keV level in Fe-56 which is up to some MeV the most strongly excited level in natural Fe.

Till 1966 the most important measurement series was that of Montague, Paul /65/ from 1962 because of the following reasons:

1. Their measurements were performed for levels in Fe-56 and Fe-54 covering a large energy range from threshold up to 3.8 MeV.

2. Measured points were obtained at very densely spaced energies in steps of 50 keV. Other measurements like those of Nishimura /66/ and also of Benjamin /67/ are not spaced densely enough in energy at least above about 1.5 MeV and those of van Patter /68/ have also only rather few measured points. Also Gilboy, Towle /69/ have only measured in steps of about 200 keV. The dense spacing, however, is needed to establish the fluctuations in the cross section.

3. The authors made a careful analysis of the corrections to be applied for multiple scattering and flux alternation in the sample. Kiehn et al. /70/, for example, did not correct their results for these effects and also van Loef, Lind /71/ made only rough estimates for this correction.

The structure in the inelastic scattering cross section of iron in the lower MeV-range is at present well defined by recent high-resolution measurements on the 845 keV level in Fe-56, since up to about 4 MeV this level gives the main contribution to the inelastic scattering in natural iron.

Barnard et al. /72/ performed in 1968 in the energy range 0.94 - 1.5 MeV in steps of 2.5 keV measurements of the excitation cross section for this level at a scattering angle of 90° with an accuracy between 5 and 7%.

Voß et al. /73/ carried out in 1970 gamma ray production cross section measurements between 0.8 and 4.5 MeV for E_{γ} = 845 keV at an average observation angle for the gamma rays of 125° with a time resolution of 0.08 nsec/m and an accuracy of about 12%.

Perey, Kinney et al. /74/ performed also an initial set of measurements on σ_n, (Fe-56) below the threshold of the 2nd excited state in Fe-56 with 0.125 nsec/m resolution by detecting the de-excitation gamma rays.

Voß et al. have in general found good agreement between their results and the results of Barnard et al. They have extended their measurements also to the higher Fe-56 levels up to about 3 MeV, but final results are not yet available. Also point measurements, i.e. measurements at selected energies, were carried out in the last years on Fe-levels by several authors, in order to determine the energy dependence of the inelastic scattering cross section in the higher MeV-range. Among the earlier ones those of

Tsukada et al. /76/ from 1961 in the energy range from 3.4 to 4.6 MeV
and of
Hopkins, Silbert /77/ from 1964 between 2 and 5 MeV

should be mentioned.

More recent measurements are those of

Almén, Wiedling et al. /75/	in 1970 between 2 and 4.5 MeV in steps of about 250 keV at an angle of 125° (relative to the (n, p)-cross section)
Kinney, Perey /78/	in 1968 between about 4 and 7.6 MeV in steps of about 40 keV on Fe-56-levels up to about 4.5 MeV
Broder et al. /79/	in 1970 from threshold up to 5.5 MeV
Boschung et al. /80/	in 1970. They measured differential inelastic scattering cross sections $\sigma_{n'}(E, \vartheta)$ for Fe-54 and Fe-56 at about 4 MeV, 5 MeV, 5.6 MeV. The cross section values integrated over the scattering angle are not given by the authors and are therefore not compared with the other above measurements.

The results of Broder et al., too, cannot be compared since they have given the total inelastic cross section values only for natural Fe. Between the other measurements a comparison is possible. Concerning the 845 keV level in Fe-56 good agreement is observed between the results of the Oak Ridge group /78/ and the Studsvik group /75/ and both data sets are compatible with that of Tsukada et al.

The results of Hopkins, Silbert, however, are much higher by a factor between 1.5 and 2.5 than the results of the three other measurement series.

Concerning the higher levels in Fe-56 the results of Hopkins et al. are compatible with those of Kinney et al. The experimental data of the Studsvik group show there a tendency to lower values in comparison with the results of the two other groups in particular for the levels higher than 2.7 MeV.

Nickel

Compared to iron much less work has been performed on inelastic neutron scattering on nickel. For the most abundant Ni-isotopes Ni-58 and Ni-60 comprehensive measurements on inelastic scattering for a number of levels were carried out by

Broder et al. in 1964 /63/ between 1.3 - 4 MeV for the levels in Ni-58 up to 3.3 MeV and in Ni-60 up to 2.2 MeV

and in 1970 /79/ between 3.5 - 5.5 MeV giving only σ_n, of natural nickel

Towle et al. in 1966 /82/ between 1.3 - 4 MeV for the levels in Ni-58 and Ni-60 up to 3.5 MeV

by Nishimura et al. /83/ in 1965 between 1.3 - 2.6 MeV for the lowest level at 1.452 MeV in Ni-58 and at 1.33 MeV in Ni-60

by Boschung et al. /80/ in 1970 between 5 and 6 MeV on Ni-58 and Ni-60

by Perey et al. /81/ in 1970 between 6.5 and 8.5 MeV on Ni-60

The two latter groups have measured primarily angular distributions for inelastic scattered neutrons at selected energies.

A comparison of the data sets from the first three measurement series shows some large discrepancies for the first excited level in Ni-60 and Ni-58. In particular for Ni-60 the results of Broder for the inelastic excitation cross section of the lowest level at 1.33 MeV are systematically higher below 2.2 MeV by about 50% than those of Towle. Above 2.2 MeV the differences are only of the order of about 20%. Nishimura's $\sigma_{n,}^{1.33}$ results are very low in comparison to the two other data sets. His curve has a pronounced minimum at 1.8 MeV. The reason for this discrepancy may perhaps be due to the fact that he used natural Ni samples and had therefore difficulties to resolve the 1.33 MeV γ-rays reliably from the 1.45 MeV line which is much stronger in natural nickel because of the 2.6 times higher abundance of Ni-58 compared to that of Ni-60. But also for inelastic scattering to the lowest level in Ni-58 at 1.45 MeV the results of Nishimura are much lower (a factor of about 1.5) than the corresponding results of Broder et al. and of Towle et al. Concerning the results of Towle et al. and Broder et al. for this level, they agree in the shape but there is a difference in the energy scale. The cross sections $\sigma_{n,}^{1.33}$ (Ni-60) and $\sigma_{n,}^{1.45}$ (Ni-58) have the same order of magnitude, but for natural nickel $\sigma_{n,}^{1.45}$ is more important because of the higher abundance of Ni-58.

In addition to the above mentioned experiments the Studsvik group /75/ has performed measurements on neutron inelastic scattering on nickel in the energy range 2 - 4.5 MeV but their results were not yet reported.

In giving here a status report of the nuclear data for the structural materials we will not touch the elastic scattering angular distributions.

They are not of crucial importance in fast power reactors since the leakage is determined by the forward scattering of the neutrons.

This part of the elastic scattering increases, however, with increasing energy whereas the energy distributions of the fission neutrons decrease with increasing energy. Furthermore an extensive and regularly updated review on the elastic scattering angular distributions is presented in BNL-400.

IV. Sodium

Resonance parameters

Sodium does not consist of more than one stable isotope namely Na-23, so that the interpretation of its resonances should be easier to perform as for iron, chromium, nickel.

The first investigations of sodium resonances were performed in transmission measurements by

Adair et al. /86/ in 1949 between 30 keV and 1 MeV and

Stelson et al. /87/ in 1952 between 120 keV and 1 MeV

In the Adair measurements 9 broad peaks were observed, the energetically lowest at 60 keV, in the Stelson measurements 12 resonances because of their better energy resolution between 2.5 and 5 keV. The parameters of them are given in Table IV.

The most extensive work on sodium resonances in earlier years was carried out by Hibdon /88/ with an energy resolution better than 1keV. He analyzed some 230 resonances in the energy region from 1 keV up to 860 keV. His main results are the following:

The few large peaks observed by Stelson and Adair in the total cross section were found to be composed of more than one resonance, a fact which is responsible for the smaller neutron widths

assigned by Hibdon compared to those of Stelson. In particular the resonance at 60 or 55 keV as found by other investigators was observed to be a superposition of a p-wave resonance at 54.1 keV with a resonance spin of 3 and a much smaller s-wave resonance at 55 keV with spin 2.

Between the larger resonance clusters a large number of smaller resonances is observed. Hibdon could assign orbital angular momenta l and spin values J to the resonances lying in the range $0 \leq l \leq 5$, $0 \leq J \leq 7$. Since Na-23 has a ground state spin of 3/2, 26 (l, J) combinations are possible for the above range of orbital angular momenta.

In the last years no adequate extensive measurement was performed than that of Hibdon. In the upper keV-range in addition to the resonance parameters of Hibdon and the earlier ones of Stelson /87/ only resonance parameters from the Karlsruhe group of Nebe et al. /99/ have become available. They analyzed their transmission data measured at the cyclotron between 0.3 and 1 MeV. Also Garg et al. /96/ have measured the total cross section in the upper keV-range up to 600 keV but large peaks were observed due to the iron canning of the sodium samples and one has to decide between the iron and sodium resonances in the measured cross section. Apart from his results for the 2.85 keV-resonance where the iron background in the total cross section can be considered as negligible no other results from his measurements are therefore given in Table IV. In the lower keV-range apart from numerous investigators of the 2.85 keV-resonance measurements on sodium resonances were carried out by

Moxon et al. /89/ in 1966. These were transmission and capture measurements covering the energy range from 200 eV to 100 keV. The authors analyzed their data for parameters of the resonances at 2.9 keV and at 54 keV. At 35 keV they observed an additional peak in the capture measurements, but they attributed it in contrary to Le Rigoleur /90/ to the aluminum canning.

Ribon et al. /91/ in 1966. These transmission measurements were carried out as consequence of the results obtained in the capture measurements of Le Rigoleur /90/ which show an important capture resonance at about 35 keV. Ribon et al. have taken care that no aluminum at all is present on the flight path of the neutrons, but in spite of this they observed in their transmission measurements a resonance at 35.4 keV.

Capture measurements were performed by

Le Rigoleur et al. /90/ in 1966 between 10 and 135 keV relative to the ^{6}Li (n,α) T-reaction cross section. Two resonances at 36 keV and 55 keV were observed. Rigoleur et al. note that assuming $l = 0$, $J = 3$ and $\Gamma_\gamma = 0.3$ eV a very low neutron width of 0.5 eV is deduced which seems not to be very probable in view of the neutron widths found by Hibdon for other p-wave resonances. Therefore the authors suggest that this resonance is due to $l \geq 2$ neutrons.

R. C. Block et al. /92/ in 1966 between about 30 keV and 700 keV but only resonance energies were determined from the measured data. These measurements were repeated and completed by

Hockenbury et al. /24/ in 1969 covering the energy range from 100 eV to about 150 keV.

Radiation widths were determined by the authors for those resonances for which neutron widths are well-known, while the resonance capture areas corrected for multiple scattering effects $\sigma_o \cdot \Gamma_\gamma$ were determined for most of the other resonances.

As already mentioned particular studies were devoted to the lowest sodium resonance at about 3 keV. The cross section up to about

40 keV is dominated by this level alone. This resonance is by far the largest resonance in sodium. It is an almost pure scattering resonance, but it has a rather unusual shape. Its asymmetric shape in particular in the high energy wing, its large width and peak height seem to indicate that it is due to s-wave neutrons. This conclusion is contradicted, however, by the absence of a dip on the low energy side characteristic for a s-wave resonance due to the interference between resonance and potential scattering. Investigations mainly of Block et al. /93/ and of Lynn et al. /94/ have led to the conclusion that this sodium resonance is due to s-wave neutrons. But conflicting opinions were encountered concerning the total angular momentum J of this resonance whether a value J = 1 or 2 has to be assigned to it. Possible peak heights of this resonance for l = 0 are about 370 barn and 630 barn corresponding to J = 1 and 2. In view of these high peak values and a width as narrow as about 300 eV it seemed in earlier years because of the too broad energy resolution in use impossible to resolve this resonance sufficiently to clearly distinguish between the two possible spin values. Among the earlier investigators were Lynn et al. /94/, Good et al. /95/, Hibdon /88/ and Garg et al. /96/. All of them performed transmission measurements and determined also the peak height of this resonance. The results for the neutron width are given in Table IV. Hibdon's value for the peak cross section was 18 barn higher than the for J = 1 theoretically expected value of 372 barn, Lynn's value obtained with a resolution of 61 eV around the resonance 12 barn lower than the theoretical value. Garg /96/ observed with an energy spread of 2 eV in the resonance a peak height cross section of 600 barn. Garg and also Hibdon concluded therefore that the spin J = 2 has to be assigned to the resonance. Lynn and also Good, who obtained good agreement of their results with those of Lynn, concluded J = 1 from their measured peak heights.

More recent studies on the 2.85 keV sodium resonance were performed by several authors. Their results are represented in Table IV.

Moxon et al. /89/ could confirm that this resonance is due to s-wave neutrons since he obtained satisfactory fits to his data only with this assumption. From the observed peak cross section he concluded a spin value J = 1.

Friesenhahn et al. /97/ carried out capture measurements in the neighbourhood (1.5 keV - 4.5 keV) of the 2.85 keV resonance. The neutron flux at 2.85 keV was determined by normalizing the measured relative flux spectrum to yield the well-known capture cross section at 0.0253 eV. For the radiation width they determined values of 0.34 eV and 0.38 eV for two different sample thicknesses using in the analysis a Γ_n-value of 410 eV.

Hockenbury et al. /98/ repeated in 1970 their capture measurements on sodium from 1969 in order to obtain the radiation width of the 2.85 keV resonance with more precision. After careful checking a program error was found in the RPI-code used for the analysis of the data measured in 1969 and in particular for estimating the multiple scattering corrections. The analysis performed with the corrected code on the experimental data from 1969 led to a radiation width of 0.45 eV for the 2.85 keV resonance in accordance with the result determined by Friesenhahn from the Hockenbury data by using the Gulf General Atomics resonance analysis code. From the new capture measurements in 1970 Hockenbury et al. obtained a radiation width (averaged over samples of different thicknesses) of 0.47 eV.

Comparing the results of these recent capture measurements a disagreement has to be noted in the radiation width determined on one side by Moxon and Hockenbury and on the other side by Friesenhahn et al. In order to obtain an upper limit for the radiation width of the 2.85 keV resonance one can assume that the entire thermal capture cross section is determined by this resonance.

Using the single level resonance formula this assumption yields a radiation width $\Gamma_\gamma = 0.34$ eV in concordance with the result of Friesenhahn but much lower than the results of Moxon and Hockenbury. The reason for this discrepancy is still unknown.

For the resonances observed above 3 keV the results of Hibdon predominate. With regard to the resonance energies good agreement is observed between Hibdon's values and the scarce results of other authors. His results for the neutron widths can only be compared for the resonance at about 54 keV with the result of Moxon, but a large difference is encountered here due to a different spin assignment by Moxon and Hibdon. Above 200 keV the results of Hibdon and for some resonances of Nebe /99/ and of Stelson /87/ are available, but they cannot be compared since in the Hibdon measurement much more resonances were observed and analyzed than in the Karlsruhe measurements /99/ so that all the neutron widths determined by Nebe et al. except for the 298 keV resonance are much higher than the corresponding values of Hibdon. The neutron widths of Nebe et al. can,however, be compared with the corresponding results of Stelson. As one sees in Table IV they are compatible with each other in the cases where both authors have observed the same resonance and assigned the same resonance spin. In the resonance energies found by them a shift of about 3 keV is observed. The information on capture widths or capture areas of sodium resonances has increased in the last years due to the measurements of Hockenbury et al. /24/.

Total cross section

Concerning the total cross section of sodium in the resonance region we have already mentioned the available measurements in the lower keV-range. The transmission measurements of Lynn et al. /94/ and of Good et al. /95/ were performed only in the vicinity of the 2.85 keV resonance. In the transmission measurement of Garg et al. the iron background has to be removed. Up to some hundred keV total cross section data are available from measurements of Moxon et al. /89/, of Hibdon /88/ and of Stelson et al. /87/. The Stelson et al. data represent fairly an average through Hibdon's better resolved results. These data seem to be somewhat too high in comparison with the low energy results of the Karlsruhe high resolution measurements on sodium of Cierjacks et al. /84/.

Cierjacks et al. /84/ measured in 1968 in the energy range between 0.3 and 30 MeV with a very good time resolution of 0.065 nsec/m below 0.9 MeV and of 0.05 nsec/m above 0.9 MeV using the neutron time-of-flight spectrometer at the Karlsruhe isochronous cyclotron.
Among the earlier measurements high resolution neutron time-of-flight studies on sodium were carried out at the Harwell synchro-cyclotron

by Langsford et al. /100/ in 1965. They measured from 200 keV up to 140 MeV with a resolution of 0.18 nsec/m.

The average cross sections of the Karlsruhe group agree well with the Langsford data although Cierjacks et al. observed in some energy regions more structure in the total cross section, very probably due to their better energy resolution. Above 6 MeV the Karlsruhe measurements do not show the same details of structure in the total cross section as found by the Harwell group.

Recently, in 1970, a new high resolution measurement on the total cross section of sodium was carried out by Stoler et al. /101/ from the Rensselaer Polytechnic Institute over the energy range from 0.5 up to 40 MeV with a very good time resolution of 0.05 nsec/m.

Im comparing the total cross sections obtained by the Karlsruhe- and the RPI-group in general good agreement is observed. The disagreement stated by Stoler et al., in particular in the cross section values in the valleys between the total cross section peaks, refers to a comparison of the RPI-results with the data of Cierjacks et al. before application of the dead time correction.

In addition to these high resolution measurements on sodium a number of total cross section measurements at selected energies exists in the MeV-range. They are not discussed here since the total cross section of sodium is well defined in this range by the high resolution measurements of the Karlsruhe- and the RPI-group.

Radiative capture cross section

We know already of the disagreement between the measured thermal capture cross section and the σ_γ-value calculated at thermal energy from the resonance parameters of the 2.85 keV resonance. But the capture cross section value at thermal energy was determined by a variety of experimental methods and is well established by them. Also recent measurements e.g. those of Yamamuro, Hockenbury et al. /98/ in the range 0.025 eV - 0.2 eV have confirmed it.

They determined a value of 0.5 barn and found a $1/v$ dependence of the capture cross section in the measured energy range. The energy dependence of the capture cross section in the range of the 2.85 keV resonance is determined by a number of measurements those of Moxon et al. /89/, Yamamuro, Hockenbury et al. /98/, Hockenbury et al. /24/ and Friesenhahn et al. /97/. On the lower energy side of this resonance higher capture cross sections, however, were obtained by Moxon et al. in comparison to the corresponding results of the RPI- /98, 24/ and GGA- /97/ group. This low energy tail seems to be characteristic (see also M.C. Moxon, Helsinki Conf. 1970 p. CN-26/32) for capture measurements using a Moxon-Rae detector since it was also observed in the capture measurements on nickel by Spitz et al. whereas the RPI-data /24/, obtained by using liquid scintillator detectors, do not show this feature.

Above the energy range of this resonance the most extensive earlier measurements were performed by Bame and Cubitt /102/ from 20 keV up to 1 MeV. Since the neutron energy spread in this experiment ranged from about 10 keV at 20 keV to 150 keV at 1 MeV, no detailed resonance structure could be observed. The more recent measurements of Le Rigoleur /90/ and of Hockenbury et al. /24/ have a better resolution. Le Rigoleur et al. have carried out only a relative measurement in the range up to 100 keV, but Hockenbury et al. performed a capture yield measurement up to 150 keV with a good time resolution between 5 nsec/m and 1.3 nsec/m. The capture cross section is well defined by these RPI-measurements, but above 150 keV up to 1 MeV only the broad resolution experiment of Bame, Cubitt exists which does not resolve the possible structure in this range. In the MeV-range very few differential measurements of the sodium capture cross section were performed by

Perkin et al. /103/ in 1957 at 14.5 MeV

Csikai et al. /104/ in 1966 at several energies between 13.4 and 15 MeV

Menlove et al. /105/ in 1966 at 17 energy points in the region between 1 MeV and 19.4 MeV. These are measurements relative to the fast fission cross section of U-235.

The result of Csikai et al. at 14.7 MeV is about 30% lower than the corresponding result of Perkin et al. But this low value is confirmed by Menlove et al. and is in excellent agreement with that of Menlove et al. At 1 MeV the experimental result of Menlove can be compared with the corresponding capture cross section of Bame, Cubitt. The agreement is satisfactory. In the vicinity of 14 MeV a peak is observed in the experimental (n,γ) cross section data of Menlove et al. It is confirmed by the measurements of Csikai et al. which indicate its position at 14.5 MeV.

Threshold reactions

In spite of the fact that the elastic and inelastic scattering cross sections represent the main part of the total cross section the threshold reactions on sodium like the (n, p), (n,α), (n, 2n) process play an important role in so far as they give above some MeV the main contribution to the neutron absorption in sodium. The present knowledge on these cross section types is therefore summarized here.

Concerning the (n, p) cross section the most important measurements are those of

Williamson et al. /106/ in 1961 between 4 and 7.9 MeV, 8.7 and 10.4 MeV and above 15 MeV

Picard, Williamson /107/ in 1963 from 14 MeV to 21 MeV and of

Bass et al. /108/ in 1965 from 5.5 MeV to 9 MeV

In addition to these experiments an extensive study on neutron reactions with proton and α-particle emission in NaJ, covering the energy range from 12.6 MeV to 18.2 MeV, was performed by Aldefeld /109/ but the (n, p) and (n,α) cross sections of sodium were not deduced from the experimental results.

A comparison of the above measurement series shows that in the overlapping energy region between 5.7 MeV and 8 MeV the results of Bass et al. are higher than those of Williamson /106/. In the range 8.5 to 9 MeV the results of Bass and Williamson agree within their error bars. Due to their good energy resolution both measurement series show considerable structure in the (n, p) cross section in the energy regions covered by them. Between 10.4 and 14 MeV, just in the region where the maximum in the (n, p) excitation function has to be expected, no experimental data are available.

With regard to the (n,α) cross section the same three measurement series of Williamson; Picard, Williamson; Bass et al. have to be mentioned as the most important ones. The energy regions covered are also the same as in the case of the (n, p) reaction except for the lower energy limits in the Bass and the Williamson experiment which were shifted to higher energies. In addition to these measurements an important one was carried out by Wölfer, Bormann /110/ in the upper MeV-range between 12.6 and 18.7 MeV. In comparison with the results of Picard, Williamson in this range the experimental data of Wölfer et al. are about 20% lower. The (n,α) values measured by Bass et al. are as in the case of the (n, p) reaction higher than the experimental results of Williamson. The largest differences are encountered around 7.4 MeV, where they amount to a factor of 1.5, and between 8.5 and 9 MeV where the results of both measurements differ by a factor of about 2. Since the (n, α) cross section has around 9 MeV the same order of magnitude as the (n, p) cross section this disagreement is of importance there and new measurements are needed to establish the energy dependence of the (n,α) cross section in this range and also above 10.5 MeV up to 12.5 MeV, where no experimental information exists up to now.

The (n, 2n) reaction is of minor importance among the threshold reactions on sodium in fast reactors because of its high threshold energy at almost 13 MeV. Three extensive measurement series exist for this cross section type, that of Picard, Williamson /107/ from 1963 between 14 and 21 MeV, of Liskien, Paulsen /111/ from 1965 between 13 and 19 MeV and of Menlove et al. /112/ from 1967 between 12.7 and 19.4 MeV. The measurements of Menlove et al. were performed relative to the fission cross section of U-235. Among these three measurements Picard et al. have obtained the lowest cross section values, Liskien et al. the highest results. At 15 MeV their results are different by a factor of 2. The differences increase with increasing energy, but the energy range above 15 MeV is no more of interest for fast reactors.

Inelastic scattering cross section

Below 4 MeV inelastic excitation cross sections for discrete levels or gamma lines have been measured by several authors and the sodium levels are well known here. At higher energies the experimental information on inelastic scattering cross sections is still scarce. The energies of the Na-23 levels are, however, known there due to recent extensive measurements of Hay et al. /70/. Spin and parity assignments are lacking for the higher levels.

Excitation level at 0.439 MeV

Among the previous measurements for the lowest level in sodium the following measurement series are of importance

that of Chien, Smith /113/ between 0.8 - 1.5 MeV has the best resolution of ± 10 keV

that of Towle, Gilboy /114/ between threshold and 2 MeV and at 2.5 15 MeV is the measurement with the highest accuracy of ± 6%

that of Lind, Day /115/ between threshold and 3.3 MeV is the most extensive measurement

that of Shipley /116/ between 3.5 and 4 MeV is the only measurement above 3.3 MeV

Lind, Day performed measurements on the gamma spectra from sodium and determined excitation functions for the 0.44 MeV line and gamma lines from the higher excited levels in sodium whereas the other authors carried out direct measurements of the inelastically scattered neutrons. More recent measurements were performed

by Perey, Kinney /74/

This is a high resolution (0.125 nsec/m) measurement on the inelastic scattering cross section of sodium in the energy range from 500 keV up to the threshold of the second excited state in sodium, i.e. up to 2.1 MeV, carried out by detecting the de-excitation gamma rays. The structure observed in the inelastic scattering cross section could be identified with well defined structure in the total cross section.

by Perey, Kinney /117/

They determined inelastic excitation cross sections for the excited sodium states up to 5.8 MeV for incident neutron energies of 5.44, 6.37, 7.6, 8.52 MeV

by Fasoli et al. /118/

They measured inelastic excitation functions for the three lowest levels in sodium in the range from 1.5 to 4 MeV in steps of 250 keV at an angle of 100^{o}.

Angular distributions for the neutrons inelastically scattered to the lowest level were reported by Chien et al. /113/, by Towle et al. /114/, by Fasoli et al. /118/, by Perey et al. /117/. The distributions are in general nearly isotropic. Only at energies above 5 MeV for which they were measured by Perey et al. larger deviations from isotropy were stated by the authors.

The results from the high resolution measurement of Perey, Kinney are compatible with those of Chien, Smith obtained with better resolution than the other measurements but with worse resolution with regard to the Perey et al. measurements. In comparison with the other experiments the experimental values of Chien, Smith previously seemed to be much too low in the range between 1.3 MeV and 1.5 MeV, whereas below 1.3 MeV good average agreement had to be stated. This discrepancy is resolved by the new measurements of Perey, Kinney. Their preliminary results show in this energy range fluctuations in the cross section ranging from the low values of Chien et al. to the higher values of Lind et al. and Towle et al. In the higher energy range the integrated (assuming isotropic angular distribution) cross section values of Fasoli et al. /118/ agree well with the corresponding results of Lind et al. and Towle et al. In comparison with the values measured by Shipley et al. which are apart from the Fasoli data the only ones available in the region 3.5 - 4 MeV, agreement is reached within the mutual experimental uncertainties, but the results of Fasoli et al. are in this range higher by a factor of about 1.3. Above 4 MeV the experimental data of Perey, Kinney at selected energies give a smooth extension of the results available below 4 MeV. No other experimental information exists in this range except for one data point at 7 MeV for which Towle et al. /119/ measured the inelastic excitation cross section for the lowest level in sodium. His result is in agreement with the experimental data of Perey et al.

Excitation levels at 2.08 and 2.39 MeV

For the second and third excited state in sodium a few measurements exist below 4 MeV. These are those

of Lind, Day /115/. They measured the excitation functions of the two gamma lines following the decay of the second level in sodium

and of one gamma line from the decay of the third excited level for incident neutron energies between threshold and 3.3 MeV.

of Freeman, Montague [120]. They carried out measurements of the inelastic excitation functions for the three lowest levels in sodium in the energy range from threshold to 3 MeV. Also in the gamma ray spectra measured they observed the two gamma lines from the two possible transitions of the second and third excited level.

of Fasoli et al. [118]. Apart from the angular distributions they determined the excitation functions for both levels considered here between about 3 MeV and 4 MeV.

of Towle, Gilboy [114]. They measured only one experimental point for the excitation cross section of these two levels at 3.97 MeV.

Above 4 MeV only a single experiment was performed by Perey, Kinney [117]. They measured apart from the angular distributions inelastic excitation cross sections for the 2.08 MeV level at 5.44, 6.37, 7.6, 8.52 MeV and for the 2.39 MeV level at 6.37, 7.6, 8.52 MeV incident neutron energy.

The experimental data point of Towle et al. [114] is for both levels slightly lower than the results of Fasoli et al. at 4 MeV. Fasoli et al. have obtained two values at about 4 MeV for each of these two levels, one by their measurements of the inelastic excitation cross section at a fixed angle of 100^{o} and the other by integration of the experimental angular distributions. A comparison can also be made between the results of Lind et al. [115] and Freeman et al. [120]. For the 2.08 MeV level the agreement is good between their results, for the 2.39 MeV level the results of Lind et al. are lower than the results of Freeman et al. This latter difference is going back to differences in the branching ratio of the two possible transitions from the 2.39 MeV level reported by both groups and due to this Lind et al. have measured the

excitation function only for the 2.39 gamma line.

Excitation levels between 2.4 MeV and 3 MeV

Three excited states are lying between 2.4 MeV and 3 MeV, at 2.64, 2.71 and 2.98 MeV. The 2.64 MeV level decays only to the ground state /121/

Lind, Day /112/ observed in the gamma ray spectra from sodium measured between threshold and 3.3 MeV the gamma line for the single possible transition from the 2.64 MeV level and also the 2.98 MeV gamma line for the transition of the 2.98 MeV level to the ground state, but this latter transition accounts only for 50% of all possible transitions.

Freeman, Montague /120/ measured gamma spectra at 2.89, 3.03, 3.20, 3.67 MeV incident neutron energy and observed the following de-excitation gamma rays

2.64 MeV from the excited state at 2.64 MeV
2.27 MeV from the excited state at 2.71 MeV
2.56 and 2.98 MeV from the excited state at 2.98 MeV

The transition of the 2.71 MeV level to the ground state was not observed.

Towle, Gilboy /114/ measured at 3.97 MeV the inelastic excitation cross section of the level doublet at 2.64/2.71 MeV and also of the level at 2.98 MeV.

Perey, Kinney /117/ determined inelastic excitation cross sections at incident neutron energies of 6.37, 7.6, 8.52 MeV for the excitation level at 2.98 MeV and the doublet of levels at 2.64/2.71 MeV.

For the 2.64 MeV level good agreement is observed between the results of Lind et al. and Freeman et al. The results of Towle et al. and Perey et al. for the level doublet 2.64/2.71 MeV do not overlap

in energy, but they are consistent. For the 2.71 MeV level no experimental information is available below about 4 MeV. The results from the several measurements on the 2.93 MeV level cannot be compared since either no overlapping energy range exists or not sufficient information on this level was obtained in one particular measurement to determine its excitation cross sections.

Excitation levels above 3 MeV

With the exception of some measurements on angular distributions of the neutrons inelastically scattered to levels above 3 MeV by Fasoli et al. /118/ the only experimental results available are those of Perey, Kinney /117/. For the excited levels up to 4.77 MeV they determined inelastic excitation cross sections at incident neutron energies of 6.37, 7.6, 8.52 MeV, for the excited states above 4.27 MeV up to 5.78 MeV at 7.6 and 8.52 MeV. The levels above 5.8 MeV could not be resolved in their measurements.

In conclusion one can say that the excitation cross section for the lowest level in sodium, which gives the main contribution to fast reactor neutron spectra, is well defined below 2 MeV. For the experimental results available above 2 MeV further confirmation would be desirable. For the higher excitation levels experimental information is mainly needed between 3 and 6 MeV.

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Table I a) Resonance parameters for Cr-5o

Er /KeV/	Γ_n /eV/ g=1	g=2	g=3	$\frac{g\Gamma_n.\Gamma\gamma}{\Gamma}$ /eV/	$\Gamma\gamma$ /eV/	l	Reference
5.49				o.o14		1	Stieglitz 7o/9/
5.5	15oo				2.9		Cotê 58 /3/
5.64	1665				3.1o	o	Stieglitz 7o
6.6	17oo					o	Bilpuch 61 /5/
9.3				o.o53		1	Stieglitz 7o
18.6				o.66		1	Stieglitz 7o
19.2				o.437		1	Stieglitz 7o
24.o				o.o58		1	Stieglitz 7o
24.8				o.365		1	Stieglitz 7o
28.43	41o					o	Beer 71 /25/
28.53	435				o.57	o	Stieglitz 7o
28.7	51o					o	Bilpuch 61
33.4				o.992		1	Stieglitz 7o
35.3				1.65o		1	Stieglitz 7o
37.32	224o					o	Beer 71
37.3	24oo				2.5	o	Stieglitz 7o
38.7	182o					o	Bilpuch 61
4o.6				o.884		1	Stieglitz 7o
43.9	65o					o	Bilpuch 61
5o.1				o.596		1	Stieglitz 7o
53.7				o.719		1	Stieglitz 7o
54.99	28o					o	Beer 71
55.3	27o				o.88	o	Stieglitz 7o
59.7				1.12o		1	Stieglitz 7o
63.4						1	Stieglitz
64.8	43					o	Beer 71
64.9						1	Stieglitz 7o
65.1	45					o	Stieglitz 7o
66						1	Stieglitz 7o
69.2						1	Stieglitz 7o
7o.5						1	Stieglitz 7o
73.5						1	Stieglitz 7o
77.8						1	Stieglitz 7o
79.4						1	Stieglitz 7o
88.9						1	Stieglitz 7o
9o.7						1	Stieglitz 7o
94.76	167o					o	Beer 71
95.o	35oo					o	Bilpuch 61
95.5	225o					o	Farrell 66 /7/
95.7	2ooo					o	Stieglitz 7o
111.79	9o					o	Beer 71
113						>o	Farrell 66
114.78	12o					o	Beer 71
116.5	155	9o				>o	Farrell 66
122						>o	Farrell 66
129.1	55o					o	Beer 71
13o	75o					o	Farrell 66
13o.5	5oo					o	Stieglitz 7o
142	353	198				>o	Farrell 66
156.6	119o					o	Beer 71
157.5	175o					o	Farrell 66
158.8	12oo					o	Stieglitz 7o

Table I a) continued

Er /KeV/	Γ_n /eV/ g=1	g=2	g=3	$\frac{g\Gamma_n \cdot \Gamma\gamma}{\Gamma}$ /eV/	$\Gamma\gamma$ /eV/	l	Reference
162.46	720					o	Beer 71
163.3	800					o	Farrell 66
164.8	600					o	Stieglitz 70
171	145					o	Stieglitz 70
185.2	3500					o	Beer 71
186.5	3000					o	Farrell 66
188.8	2500					o	Stieglitz 70
218.54	160					o	Beer 71
231.71	920					o	Beer 71
232.5	1500					o	Farrell 66
237.6	650					o	Stieglitz 70
245.66	200					o	Beer 71
252.3	250					o	Stieglitz 70
258	500					o	Farrell 66
276.72	1720					o	Beer 71
278	2500					o	Farrell 66
280.6	1500					o	Stieglitz 70
283.5						>o	Farrell 66
292	6000					o	Farrell 66
296.4	3700					o	Stieglitz 70
307	1500					o	Farrell 66
313.5		650				>o	Farrell 66
322	7000					o	Farrell 66
327.7	500					o	Farrell 66
328.6	4500					o	Stieglitz 70
341.0						>o	Farrell 66
348						>o	Farrell 66
353	5500					o	Farrell 66
356.6	4500					o	Stieglitz 70
359.5	1750					o	Farrell 66
370	10000					o	Farrell 66
381	688	240				>o	Farrell 66
388.5	4000					o	Farrell 66
395.0	250					o	Farrell 66
405		500				>o	Farrell 66
413.7	1750					o	Farrell 66
416.5	14000					o	Farrell 66
431.5		500				>o	Farrell 66
433.5	10000					o	Farrell 66
442						>o	Farrell 66
454.5	250					o	Farrell 66
459.5	750					1	Farrell 66
467.5	6500					o	Farrell 66
472	750					1	Farrell 66
478	2500					o	Farrell 66
489	1750					o	Farrell 66
502,5	4000					o	Farrell 66
509						>o	Farrell 66
523	500					o	Farrell 66
536						>o	Farrell 66
538.5	3000					o	Farrell 66
547	2500					o	Farrell 66
553.8	6000					o	Farrell 66
560.5	3000					o	Farrell 66
578	2700					o	Farrell 66
580,5	7000					o	Farrell 66
590.7	1500					o	Farrell 66

Table I b) Resonance parameters for Cr-52

Er /KeV/	gΓn /eV/	Γ_n /eV/ g=1	g=2	g=3	$\frac{g\Gamma n\Gamma\gamma}{\Gamma}$ /eV/	gΓγ /eV/	Γγ /eV/	l	Reference
1.626					o.o8			1	Stieglitz 7o/9/
22.9	1.o9				o.549	1.11		1	Stieglitz 7o
22.9	5							1	Beer 71/25/
27.6					o.458			1	Stieglitz 7o
31.6	3.95				o.3o8	o.34		1	Stieglitz 7o
31.615	14.6							o	Beer 71
33.9					o.336			1	Stieglitz 7o
34.3					o.258			1	Stieglitz 7o
48.3					o.931			1	Stieglitz
5o.189		1714						o	Beer 71
5o.2		175o					1.16	o	Stieglitz 7o
51		155o						o	Bilpuch 61/5/
57.577	79							1	Beer 71
57.8	1o.7				o.72o	o.77		1	Stieglitz 7o
79.2					o.38o			1	Stieglitz 7o
93.5		7ooo						o	Bowman 62/6/
96.23		64oo						o	Beer 71
96.5		59oo						o	Bilpuch 61
97.1		78oo					4.8o	o	Stieglitz 7o
98		32oo						o	Hibdon 57
1o6	59.8							1	Beer 71
1o7					o.857			1	Stieglitz 7o
111					o.624			1	Stieglitz 7o
111.61	59.7							1	Beer 71
113					1.349			1	Stieglitz 7o
116								1	Stieglitz 7o
118	31							o	Beer 71
119		8oo						o	Bowman 62
12o.4		6oo							Hibdon 57/2/
121.38		612						o	Beer 71
123.2		56o						o	Stieglitz 7o
124					1.47o			1	Stieglitz 7o
13o		26o	15o	11o				> o	Bowman 62
13o.1o	216							1	Beer 71
132	22o				1.328	1.34		1	Stieglitz 7o
138		1ooo							Hibdon 57
138		7ooo						o	Bowman 62
139.5		75oo						o	Bilpuch 61
139.71		543o						o	Beer 71
141.33		66o						o	Beer 71
141.4		75oo					2.o7	o	Stieglitz 7o
142		12oo							Hibdon 57
146		8oo							Hibdon 57
152		8oo							Hibdon 57
155					o.618			1	Stieglitz 7o
168					o.838			1	Stieglitz 7o
197		115	61	47				> o	Bowman 62
199		111	63	45				> o	Bowman 62
2o5		12o	65	5o				> o	Bowman 62
212		37o	2oo	15o				> o	Bowman 62

Table I b) continued

Er /KeV/	gΓn /eV/	Γn /eV/ g=1	g=2	g=3	$\frac{g\Gamma n\Gamma\gamma}{\Gamma}$ /eV/	gΓγ /eV/	Γγ /eV/	l	Reference
216		32o	17o	12o				> o	Bowman 62
224		<1oo						> o	Bowman 62
229		31o	18o	12o				> o	Bowman 62
233.95	297							1	Beer 71
235		16oo						o	Bowman 62
235.83	1o7o							1	Beer 71
239.4		1ooo						o	Stieglitz
241		13o	67	52				> o	Bowman
241.6	22o							1	Beer 71
243		15oo							Hibdon 57
246		11oo	57o	41o				> o	Bowman 62
246.29	1o1o							1	Beer 71
249.26	55o							o	Beer 71
25o		126o	67o	47o				> o	Bowman 62
252		< 1oo						> o	Bowman 62
256		75o	41o	29o				> o	Bowman 62
256.67	31o							1	Beer 71
258		23o	123	9o				> o	Bowman 62
264		28o	15o	11o				> o	Bowman 62
268		< 1oo						> o	Bowman 62
272		21o	112	82				> o	Bowman 62
281		1o4o						o	Bowman 62
281.89	55o							1	Beer 71
285.4		62o						o	Stieglitz 7o
289		< 1oo						> o	Bowman 62
3o3		382	2o2	146				> o	Bowman 62
31o		575	324	242				> o	Bowman 62
315		< 1oo						> o	Bowman 62
326		7ooo						o	Bowman 62
343		532	3o3	219				> o	Bowman 62
349		138	76	55				> o	Bowman 62
363.5		35oo						o	Bowman 62
374		346	198	157				> o	Bowman 62
383		3o8	174	123				> o	Bowman 62
395		5o1	263	194				> o	Bowman 62
4o1		18oo						o	Bowman 62
418		1ooo						o	Bowman 62
442		77o	428	3o8				> o	Bowman 62
458		<1oo						> o	Bowman 62
46o.5		12oo						o	Bowman 62
485		318	162	122				> o	Bowman 62
53o		8ooo						o	Bowman 62
533		748	374	268				> o	Bowman 62
549		627	32o	237				> o	Bowman 62
553		<1oo						> o	Bowman 62
559		512	224	2oo				> o	Bowman 62
565		<1oo						> o	Bowman 62
57o		<1oo						> o	Bowman 62
575		15o4	786	576				> o	Bowman 62
581		<1oo						> o	Bowman 62
587		<1oo						> o	Bowman 62
6o3		538	321	229				> o	Bowman 62

Table I b) continued

Er /KeV/	gΓn /eV/	Γ n /eV/ g=1	g=2	g=3	$\frac{g\Gamma n\Gamma\gamma}{\Gamma}$ /eV/	gΓγ /eV/	Γγ /eV/	l	Reference
608		20000						o	Bowman 62
609		843	390	284				> o	Bowman 62
617		723	388	280				> o	Bowman 62
624		487	265	189				> o	Bowman 62
628.5		1500						o	Bowman 62
630		450	245	175				> o	Bowman 62
636		788	424	301				> o	Bowman 62

Table I c) Resonance parameters for Cr-53 I = 3/2

Er /KeV/	2g Γn /eV/	Γn /eV/	g Γn.Γγ / Γ /eV/	Γγ /eV/	l	J	Reference
3,6	157						Good 65 /4/
4,185		152o		3,23	o	1	Stieglitz 7o /9/
4,2	445						Good 65
4,25		~1oo			o	2	Hibdon 57 /2/
5,4							Hibdon 57
5,4	212						Good 65
5,67		22o		1,33	o	2	Stieglitz 7o
6,3							Hibdon 57
6,6	357						Good 57
6,74		12oo		5,28	o	1	Stieglitz 7o
7,2							Hibdon 57
8,o							Hibdon 57
8,o	1o73						Good 65
8,18		1o3o		3,25	o	2	Stieglitz 7o
8,8							Hibdon 57
1o,5							Hibdon 57
1o,5	224						Good 65
12,1			o,185		1		Stieglitz 7o
12,9			o,11o		1		Stieglitz 7o
14,6			o,13o		1		Stieglitz 7o
19,3	132						Good 65
19.53		13o			o	2	Müller,Rohr 69/8/
19,75		1o7		o,78	o	2	Stieglitz 7o
2o,2			o,385		1		Stieglitz 7o
22,4			o,145		1		Stieglitz 7o
25.3	237						Good 65
25,64		22o			o	2	Müller, Rohr 63
25,95		235		o,61	o	2	Stieglitz
26,4	3,5o						Good 65
26,95		7oo			o	1	Müller, Rohr 69
27,24		76o		1,57	o	1	Stieglitz 7o
28,8	555						Good 65
28,8			o,65o		1		Stieglitz 7o
29,23		33o			o	2	Müller,Rohr 69
29,57		36o		1,21	o	2	Stieglitz 7o
31,5			o,31o		1		Stieglitz 7o
32			o,23o		1		Stieglitz 7o
34,9			o,32o		1		Stieglitz 7o
37,7			o,35o		1		Stieglitz 7o
42,4			o,21o		1		Stieglitz 7o
43,2			o,2oo		1		Stieglitz 7o
47,1			o,37o		1		Stieglitz 7o
49,8			-		1		Stieglitz 7o
51,o			-		1		Stieglitz 7o
53,5			o,4oo		1		Stieglitz 7o
64,8			o,595		1		Stieglitz 7o
65,7		45oo			o	2	Müller,Rohr 69
66,1		51oo		o,8o	o	2	Stieglitz 7o
68							Hibdon 57
69,7			1,25		1		Stieglitz 7o
73,1		1o5o			o	1	Müller, Rohr 69
74,o6		12ðo			o	2	Müller,Rohr 69
74,6		1ooo			o	2	Stieglitz 7o

Table I c) continued

Er /KeV/	2gΓn /eV/	Γn /eV/	$\frac{g\Gamma n.\Gamma\gamma}{\Gamma}$ /eV/	Γγ /eV/	l	J	Reference
87,2		78oo			o	1	Müller,Rohr 69
87,7		42oo			o	1	Stieglitz 7o
94,5		6oo			o	2	Müller,Rohr 69
95,5		34o			o	(1)	Stieglitz
99,7		4oo			o	1	Müller,Rohr 69
1o6							Hibdon 57
1o7,4		15oo			o	2	Müller,Rohr 63
1o9		145o			o	1	Stieglitz 7o
123,6		4ooo			o	1	Müller,Rohr 69
124,5		5oo			o	2	Müller,Rohr 69
127,6		4oo			o	2	Müller,Rohr 69
129,5		2oo			o	2	Müller,Rohr 69
135,o		24ooo			o	1	Müller,Rohr 69
145,9		6oo			o	2	Müller,Rohr 69
157,8		3oo			o	2	Müller,Rohr 69
159,o		2ooo			o	2	Müller,Rohr 69
161,7		24oo			o	2	Stieglitz 7o
163,5							Hibdon 57
172,7		12oo			o	2	Müller,Rohr 69
175,7		4ooo			o	1	Müller,Rohr 69
176		17oo			o	2	Stieglitz 7o
183		35oo			o	1	Müller,Rohr 69
186		5oo			o	2	Müller,Rohr 69
195,7		6oo			o	2	Müller,Rohr 69
2o1,7		55o			o	2	Müller,Rohr 69
221,6		42oo			o	2	Müller,Rohr 69
227,5		3oo			o	2	Müller,Rohr 69
239		3ooo			o	2	Müller,Rohr 69
244,5		4ooo			o	1	Müller,Rohr 69
246		5oo			o	2	Müller,Rohr 69

Table I d) Resonance parameters for Cr-54

Er /KeV/	Γ_n /eV/ g = 1	g = 2	$\frac{g\Gamma n\Gamma\gamma}{\Gamma}$ /eV/	$\Gamma\gamma$ /eV/	l	Reference
1o.3			o.143		1	Stieglitz 7o /9/
14.4			o.281		1	Stieglitz 7o
19.1			o.254		1	Stieglitz 7o
23.1	59o			o.19o	o	Stieglitz 7o
23.5	49o				o	Bilpuch 61 /5/
26.5	5oo				o	Bilpuch 61
51.1			o.342		1	Stieglitz 7o
54.9			o.355		1	Stieglitz 7o
67.5			o.938		1	Stieglitz 7o
76.4					1	Stieglitz 7o
9o.1					1	Stieglitz 7o
116.4	5ooo				o	Farrell 66 /7/
119	22oo				o	Bilpuch 61
12o.1	56oo				o	Stieglitz 7o
129	25o				o	Farrell 66
169.8	5oo	25o			>o	Farrell 66
175	17oo				o	Farrell 66
179.1	19oo				o	Stieglitz 7o
189.3	25o	13o			>o	Farrell 66
228					>o	Farrell 66
233					>o	Farrell 66
247.5	125o				1	Farrell 66
264					>o	Farrell 66
279.5	9ooo				o	Farrell 66
282.5	3ooo				o	Farrell 66
285	3oo	15o			>o	Farrell 66
288.4	95oo				o	Stieglitz 7o
29o.5	6oo				o	Farrell 66
3oo.5	5oo				o	Farrell 66
314					>o	Farrell 66
325	16ooo				o	Farrell 66
332	8oo	41o			>o	Farrell 66
333.3	1oooo				o	Stieglitz 7o
342	2oo				o	Farrell 66
351.5	5oo				o	Farrell 66
355.1	3ooo				o	Stieglitz 7o
355.5	3oo				o	Farrell 66
358.7	4oo	2oo			>o	Farrell 66
362	5oo				0	Farrell 66
387.5	1o35	52o			>o	Farrell 66
393.5	4ooo				o	Farrell 66

Table II a) Resonance parameters for Fe-54

Er /KeV/	Γ_n /eV/	g Γn /eV/	$\frac{g\Gamma n\Gamma\gamma}{\Gamma}$ /eV/	σoΓγ /beV/	Γγ /eV/	J	l	Reference
7.25	1ooo							Bilpuch 61 /5/
7.25					≤ 3			Moxon 65 /18/
7.67	1o1o						o	Beer 71 /26/
7.757	1o2o					o.5		Garg 64/71 /22/
7.82								Hockenbury 69/24/
9.4			o.6					Moxon 65
9.48			o.51	14o				Hockenbury 69
11.19		7					> o	Beer 71
3o.7o		1o					> o	Beer 71
39.18		15					> o	Beer 71
52.5	21oo							Bilpuch 61
52.5	254o					o.5		Garg 64/71
52								Hockenbury 69
52.78	216o						o	Beer 71
55.4o		3o					> o	Beer 71
72	16oo							Bilpuch 61
71.8	248o					o.5		Garg 64/71
71.86	177o						o	Beer 71
92								Hibdon 57 /2/
98	4oo						o	Bowman 62 /6/
98.5	58o					o.5		Garg 64/71
98.5	51o						o	Beer 71
1o2.8	1375							Bilpuch 61
1o2	59o					o.5		Garg 64/71
128.5	95o					o.5		Garg 64/71
129.6	3ooo						o	Beer 71
13o	23oo							Bilpuch 61
13o	127o						o	Bowman 62
137.5	118o						o	Garg 64/71
147	28oo							Bilpuch 61
146	151o						o	Bowman 62
147.1	275o						o	Beer 71
147.2	355o					o.5		Garg 64/71
153								Hibdon 57
159	18o						o	Beer 71
163	11o(g=1) 64(g=2) 49(g=3)						> o	Bowman 62
163	53o					o.5		Garg 64/71
163.9		83					> o	Beer 71
172.5								Garg 64/71
173	48oo						o	Bowman 62
173.9	285o						o	Beer 71
18o								Hibdon 57
188.5	38ooo						o	Bowman 61
191.2	424oo						o	Beer 71
223	19oo						o	Bowman 62
222.8	157o						o	Beer 71
23o	5oo						o	Bowman 62
23o.2	26o						o	Beer 71
24o								Hibdon 57
244.5	13ooo						o	Bowman 62
245.7	246oo						o	Beer 71
245.o	239(g=1) 12o(g=2) 82(g=3)						o	Bowman 62

at higher energies only results of Bowman 62; tabulated in BNL 325 (1966)

Table II b) Resonance parameters for Fe - 56

Er /KeV/	Γ_n /eV/ g=1	g=2	g=3	$2g\Gamma_n$ /eV/	$g\Gamma_n \cdot \Gamma\gamma / \Gamma$ /eV/	$\sigma_o \Gamma\gamma$ /beV/	$\Gamma\gamma$ /eV/	l	J	Reference
1.167										Garg 64 /23/
1.18				o.1o4						Moxon 65 /18/
1.2	o.o56						o.673	o		Moore 63 /17/
1.15										Hockenbury 69/24/
					not all references		for this resonance listed			
2.35					o.ooo4	o.42				Hockenbury 69
11.2					o.o43	1o.2				Hockenbury 69
22					o.2					Macklin 64 /19/
22.7										Moxon 65
22.7					o.191	21.9				Hockenbury 69
22.79					o.15					Ernst 7o/22/
28.3	167o									Bilpuch 61
29.2	5oo									Hibdon 57 /2/
28.o	16oo						1.5	o		Macklin 64
27.66	152o								o.5	Garg 64/71
27.68							1.4	o		Ernst 7o
27.7							1.44			Hockenbury 69
27.7							≤1.3			Moxon 65
34.1										Hockenbury 69
34.25					o.53			(1)		Ernst 7o
36					1.9					Macklin 64
36.6					o.3o1	21.4				Hockenbury 69
36.69					o.28			(1)		Ernst 7o
38.3					o.46	3o.1				Hockenbury 69
38.38					o.32			(1)		Ernst 7o
45.8					o.32	18.7				Hockenbury 69
46.o5					o.44			(1)		Ernst 7o
5o	44	29					$g\Gamma\gamma$:1.9	> o		Macklin 64
51.9					o.51	25.6				Hockenbury 69
52.2					o.68			(1)		Ernst 7o
53.3					o.54	26.4				Hockenbury 69
53.6					o.38			(1)		Ernst 7o
55					o.14	6.7				Hockenbury 69
59					o.54	24.2				Hockenbury 69
59.25					o.72			(1)		Ernst 7o
63.1										Hockenbury 69
63.45					o.61			(1)		Ernst 7o
74	425									Bilpuch 61
75.6	9oo									Hibdon 57
73.9	54o								o.5	Garg 64 /71
72.6										Hockenbury 69
73.2								(1)		Ernst 7o
74.o	539							o		Rohr 66 /2o/
76.7										Hockenbury 69
77.o								(1)		Ernst 7o
8o.4										Hockenbury 69
8o.9										Ernst 7o
82-84	unresolved									Hockenbury 69
83.5	1o4o									Bilpuch 61
83.5	912						o.9	o		Rohr 66
83.6	1o3o								o.5	Garg 64 /71
85.5	98o									Hibdon 57
9o										Hockenbury 69
9o.3	4o	2o					g=1 g=2 1.2 o.6	(1)		Rohr 66

Table II b) continued

Er /KeV/	Γ_n /eV/ g=1	g=2	g=3	$2g_n$ /eV/	$g\Gamma_n \cdot \Gamma\gamma / \Gamma$ /eV/	$\sigma_o \Gamma\gamma$ /beV/	$\Gamma\gamma$ /eV/	l	J	Reference
92.1										Hockenbury 69
93.					1.52			(1)		Ernst 7o
95.9										Hockenbury 69
96.6					1.4o			(1)		Ernst 7o
98.5	7o				o.4		o.4	o		Rohr 66
1o2										Hockenbury 69
1o3					1.5			(1)		Ernst 7o
1o5										Hockenbury 69
1o6.3					1.2o			(1)		Ernst 7o
112										Hockenbury 69
112.8					1.1o			(1)		Ernst 7o
124	13o									Bilpuch 61
127.5	5oo									Hibdon 57
122.5	14?								o.5	Garg 64/71
123.5	125						2.7	o		Rohr 66
124										Hockenbury 69
129										Hockenbury 69
13o.2							1.4	o		Rohr 66
129.6	66o								o.5	Garg 64/71
131	4oo									Bilpuch 61
132								o		Ernst 7o
138	8oo									Hibdon 57
139.9	227o								o.5	Garg 64/71
141.5	246o						2.8	o		Rohr 66
141.5	2365									Bilpuch 62
145	8oo									Hibdon 57
147.5								(1)		Ernst 7o
151								(1)		Ernst 7o
153								(1)		Ernst 7o
162	875									Hibdon 57
163								(o)		Ernst 7o
169	63o									Bilpuch 61
168.7	76o								o.5	Garg 64/71
169.o	87o							o		Rohr 66
182								(1)		Ernst 7o
186.5	35oo							o		Bowman 62/6/
187	32oo								o.5	Garg 64/71
188.o	343o							o		Rohr 66
188	1ooo									Hibdon 57
189	248o									Bilpuch 61
199								(1)		Ernst 7o
2o8								(1)		Ernst 7o
219	6oo									Hibdon 57
219	147o							o		Rohr 66
22o										Bilpuch 61
22o	13oo							o		Bowman 62
221										Garg 64/71
222								(1)		Ernst 7o
232								(1)		Ernst 7o
239								(1)		Ernst 7o
243.5	3oo							o		Bowman 62
243.o	63o							o		Rohr 66
265	11o	59	44					> o		Bowman 62
267	< 1oo									Bowman 62
272	2ooo									Hibdon 57
273	35oo							o		Bowman 62

at higher energies only results of Bowman and Hibdon, tabulated in BNL 325 (1966)

Table II c) Resonance parameters for Fe-57 I = 1/2

Er /KeV/	Γ_n /eV/	$2g\Gamma_n$ /eV/	$\frac{g\Gamma_n\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\,\Gamma\gamma$ /beV/	$\Gamma\gamma$ /eV/	l	J	Reference
1.63			o.o5o	79.6				Hockenbury 69(24)
3.96					1.14			Hockenbury 69
3.87	177							Good 65/4/
4	22o				≤ 1			Moxon 65/18/
3.9	22o					o	o	Miller 59 /31/
4.75			o.o51	28				Hockenbury 69
6	65o							Bilpuch 61 /5/
6.1	42o				1.7			Moxon 65
6.1	396							Good 65
6.28	24oo							Garg 64 /71/23/
6.1	42o							Müller 59
6.21					1.32			Hockenbury 69
7.22			o.36	132				Hockenbury 69
7.9o			o.18	6o				Hockenbury 69
12.7			1,4					Moxon 65
12.7			2.o					Macklin 64 /19/
12.7								Miller 59
12.8			o.42					Hockenbury 69
13.9			o.7o	122				Hockenbury 69
17.o			1.5					Macklin 64
17.5			2.2					Moxon 65
18			o.52	76.5				Hockenbury 69
2o.5			1.8					Macklin 64
21.3			1.o9	135				Hockenbury 69
27								Macklin 64
27.7					1.3			Moxon 65
28.3								Hockenbury 69
28.7	3o18							Good 65
29.15	345o						1	Rohr 69 /21/
29.o					4			Hockenbury 69
4o					6			Hockenbury 69
4o.5		1258						Good 65
41.4	1ooo						1	Rohr 69
45.5		4o4						Good 65
47.o5	45o						1	Rohr 69
55.81	1oooo						o	Rohr 69
61	37oo						1	Rohr 69
77.2	195o						1	Rohr 69
93.7	2oo						1	Rohr 69
1o9.6	23oo						1	Rohr 69
11o.15	12oo						1	Rohr 69
125	15oo						1	Rohr 69
126	25oo						o	Rohr 69
129.5	42oo						1	Rohr 69
134.5	33oo						o	Rohr 69
141	15oo						o	Rohr 69
143								Hibdon 57
149								Hibdon 57
163.3								Garg 64/71
167.3	11oo						1	Rohr 69
169	17oo						1	Rohr 69
176.3	7oo						o	Rohr 69
185.5	35oo						1	Rohr 69
189.5	32oo						o	Rohr 69

Table II d) Resonance parameters for Fe-58

Er /KeV/	Γ_n /eV/	$\frac{g\Gamma_n\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma\gamma$ /beV/	$\Gamma\gamma$ /eV/	l	Reference
o.23o	-	o.oo65	74.1	-		Hockenbury 69 /24/
o.359	-	o.o17	124	-		Hockenbury 69
2.82	-			-		Hockenbury 69
4.96	-			-		Hockenbury 69
6.16	-			-		Hockenbury 69
9.29	-			-		Hockenbury 69
1o.4	-			-		Hockenbury 69

Table III a, Resonance parameters for Ni-58

Er /KeV/	Γ_n /eV/ g=1	g=2	$g\Gamma_n\Gamma_\gamma/\Gamma$ /eV/	$\sigma_o\Gamma_\gamma$ /beV/	Γ_γ /eV/	l	J	Reference
- 28.5	Γ_n^o:7o							Bilpuch 61/5/
- 28.5	" :98							Garg 64/71/23/
6.89			o.o22	8.3				Hockenbury 69/24/
12.6								Hockenbury 69
13.3			o.32	63.2				Hockenbury 69
13.34			o.49			1?		Fröhner 72/32/
13.6			o.52	1o1				Hockenbury 69
13.66			o.63			1?		Fröhner 72
14-16	not resolved							Hockenbury 69
15.3	114o						1/2	Garg 64/71
15.4	12oo				2.1	o		Fröhner 72
16.5	154o					o		Bilpuch 61
16.5								Hockenbury 69
17.2								Hockenbury 69
19.o								Hockenbury 69
19.o3			o.o8			1?		Fröhner 72
2o			o.2o	26.o				Hockenbury 69
2o.o4			o.24			1?		Fröhner 72
21.1			o.56	7o.o				Hockenbury 69
21.16			o.57			1?		Fröhner 72
26.o8			o.25			1?		Fröhner 72
26.6			o.7	68				Hockenbury 69
26.67			o.73			1?		Fröhner 72
32.36			1.26			1?		Fröhner 72
32.4			1.44	114				Hockenbury 69
34.2			o.65	49.5				Hockenbury 69
34.24			o.69					Fröhner 72
36.1			o.86	62				Hockenbury 69
36.12			1.o1			1?		Fröhner 72
39.5								Hockenbury 72
39.59			o.66					Fröhner 72
47.8			o.98			1?		Fröhner 72
47.9			1.58	87.5				Hockenbury 69
52.o			1.46			1?		Fröhner 72
52.1			o.32	16.2				Hockenbury 69
54.7			o.28			1?		Fröhner 72
54.8								Hockenbury 69
58.6			o.52			1?		Fröhner 72
6o.1			o.44			1?		Fröhner 72
6o.1								Hockenbury 69
61.75			o.71			1?		Fröhner 72
61.8								Hockenbury 69
63	36oo				3.2	o		Fröhner 72
63.2	365o						o5	Garg 64/71
63.5	3555					o		Bilpuch 61
66.4			o.36			1?		Fröhner 72
66.4								Hockenbury 69
68.75			o.24			1?		Fröhner 72
69.8o			o.46			1?		Fröhner 72
77.95			o.12			1?		Fröhner 72
78.2								Hockenbury 69
81.1			o.73			1?		Fröhner 72

Table III a, Resonance parameters for Ni-58 (continued)

Er /KeV/	Γ_n /eV/ g=1	Γ_n /eV/ g=2	$g\Gamma_n\Gamma_\gamma/\Gamma$ /eV/	$\sigma_o\Gamma_\gamma$ /beV/	Γ_γ /eV/	l	J	Reference
81.3								Hockenbury 69
83								Hockenbury 69
83.1	11o				3.5	o		Fröhner 72
89.84			o.45			1?		Fröhner 72
92.25			o.17			1?		Fröhner 72
94.45			o.9			1?		Fröhner 72
95.9								Hockenbury 69
97.o			o.5			1?		Fröhner 72
1o1								Hockenbury 69
1o1.1			1.o			1?		Fröhner 72
1o5								Hockenbury 69
1o5.3			1.8					Fröhner 72
1o7								Hockenbury 69
1o7	2ooo					o		Farrell 66/7/
1o7.7	15oo				3.5	o		Fröhner 72
1o8	147o						o.5	Garg 64/71
1o8.5	1o2o					o		Bilpuch 61
11o								Hockenbury 69
11o.7			1.3			1?		Fröhner 72
117.5			o.8			1?		Fröhner 72
12o								Hockenbury 69
12o.3			3.3			o?		Fröhner 72
122.5	1ooo					o		Farrell 66
123.8	74o						o.5	Garg 64/71
124	5oo					o		Bilpuch 61
124								Hockenbury 69
125	75o				3,2	o		Fröhner 72
136	3ooo					o		Farrell 66
137.5	176o						o.5	Garg 64/71
138.5	3ooo					o		Farrell 66
138.5	6885					o		Bilpuch 61
14o.5	346o						o.5	Garg 64/71
147.5	16o	95				> o		Farrell 66
157	625o					o		Farrell 66
157	437o					o		Bilpuch 61
159	738o						o.5	Garg 64/71
167.5	5oo					o		Farrell 66
183.5	227	135				> o		Farrell 66
19o.5	3ooo					o		Farrell 66
192	4o5o						o.5	Garg 64/71
191.5	3ooo					o		Bilpuch 61
2o4.5	75oo					o		Farrell 66
2o6.5	768o					o		Bilpuch 61
2o7	6o3o					o		Garg 64
215	245	14o				> o		Farrell 66
231	6ooo					o		Farrell 66
235							o.5	Garg 64
243	25o					o		Farrell 66
247.5	343	192				> o		Farrell 66
257.5						> o		Farrell 66
27o	6ooo					o		Farrell 66
274								Garg 64

Table III a, Resonance parameters for Ni-58 (continued)

Er /KeV/	Γ_n /eV/ g=1	Γ_n /eV/ g=2	$\frac{g\Gamma_n\Gamma_\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma_\gamma$ /beV/	Γ_γ /eV/	l	J	Reference
278	2000					o		Farrell 66
282								Garg 64
286.5	200	115				> o		Farrell 66
303.5	750					o		Farrell 66
306.5						> o		Farrell 66
325	2000					o		Farrell 66
334.5	592	328				> o		Farrell 66
343.5	560	305				> o		Farrell 66
349	1500					o		Farrell 66
357.5	426	230				> o		Farrell 66
367	250					o		Farrell 66
378.5	480	260				> o		Farrell 66
394	750					o		Farrell 66
396						> o		Farrell 66
413						> o		Farrell 66
416						> o		Farrell 66
417,5	5000					o		Farrell 66
426		500				> o		Farrell 66
426.5	8000					o		Farrell 66
435.5						> o		Farrell 66
446						> o		Farrell 66
451						> o		Farrell 66
454.5	3000					o		Farrell 66
458.5						> o		Farrell 66
461.5	750					o		Farrell 66
492.5	1987	1023				> o		Farrell 66
495.5	2000					o		Farrell 66
507	2000					o		Farrell 66
508						> o		Farrell 66
512.5						> o		Farrell 66
522.5	750					o		Farrell 66
530	422	220				> o		Farrell 66
544	640	322				> o		Farrell 66
554.5	1250					> o		Farrell 66
559.5	1260	633				> o		Farrell 66
571.0	10000					o		Farrell 66
588.5	2500					o		Farrell 66
600	6000					o		Farrell 66

Table III b) Resonance parameters for Ni-6o

Er /KeV/	Γn /eV/	$g\Gamma_n\Gamma_\gamma/\Gamma$ /eV/	$\sigma_o\,\Gamma_\gamma$ /beV/	Γγ /eV/	l	J	Reference
1.292		o.ooo3			1		Stieglitz 7o/9/
1.294							Hockenbury 69 / 24/
2.257		o.o68			1		Stieglitz 7o
2.26		o.o65	75.7				Hockenbury 69
5.52		o.o55	25.9				Hockenbury 69
5.53		o.o56					Stieglitz 7o
12.2		o.17	37				Hockenbury 69
12.2		o.o42			1		Stieglitz 7o
12.23		o.o9			1 ?		Fröhner 72 /22/,/32/
12.4	191o					o.5	Garg 64/71/23/
12.47	266o			3.3o	o		Stieglitz 7o
12.5	265o			3.4	o		Fröhner 72
13.6		o.o9o			1		Stieglitz 7o
13.62		o.14			1 ?		Fröhner 72
13.8							Hockenbury 69
12-14	not resolved						Hockenbury 69
14.5	26oo				o		Bilpuch 61/ 5/
23.8		o.921			1		Stieglitz 7o
23.8		o.78	85.7				Hockenbury 69
23.88		o.6			1 ?		Fröhner 72
28.47 ?		o.o8			1 ?		Fröhner 72
28.5		o.26	23.2				Hockenbury 69
28.64	8oo			1.1			Stieglitz 7o
28.6	9oo			1.2	o		Fröhner 72
28.65	69o					o.5	Garg 64 /71
3o.	11oo				o		Bilpuch 61
29.47		o.o9			1 ?		Fröhner 72
3o.1		o.321			1		Stieglitz 7o
3o.2		o.39	33				Hockenbury 69
3o.24		o.31			1 ?		Fröhner 72
32.9		o.351			1		Stieglitz 7o
33.o3		o.33			1		Fröhner 72
33.4							Hockenbury 69
39.4		o.565			1		Stieglitz 7o
39.54		o.41			o ?		Fröhner 72
39.5							Hockenbury 69
42.93	12o			1.o	o		Fröhner 72
42.9		o.77	47				Hockenbury 69
43.o8	77			1.73	o		Stieglitz 7o
43.1	14o					o.5	Garg 64/71
47.4		o.862			1		Stieglitz 7o
47.6	~ 1o	o.78		1.o	o ?		Fröhner 72
49.6		o.257			1		Stieglitz 7o
49.8		o.27			1 ?		Fröhner 72
5o.8					1		Stieglitz 7o
5o.99		o.11			1 ?		Fröhner 72
51.5		o.456			1		Stieglitz 7o
51.64		o.38			1		Fröhner 72
51.9							Hockenbury 69
52.7					1		Stieglitz 7o
56.o		o.15			1 ?		Fröhner 72
56.3		o.374			1		Stieglitz 7o

Table III b) continued

Er /KeV/	Γ n /eV/	$\frac{g\Gamma_n\Gamma_\gamma}{\Gamma}$ /eV/	σoΓγ /beV/	Γγ /eV/	l	J	Reference
56.74		o.45			1 ?		Fröhner 72
56.9		o.416			1		Stieglitz 7o
57.o							Hockenbury 69
65.13	39o			2.43	o		Stieglitz 7o
65.2							Hockenbury 69
65.3	81o					o.5	Garg 64/
65.42	5oo			2.o	o		Fröhner 72
66	7oo				o		Bilpuch 61
71.51		o.33			1 ?		Fröhner 72
71.3		o.396			1		Stieglitz 7o
72.8							Hockenbury 69
73.2		o.61o			1		Stieglitz 7o
73.25		o.44			1 ?		Fröhner 72
78.2		o.3o8			1		Stieglitz 7o
78.26		o.19			1 ?		Fröhner 72
79.9		o.447			1		Stieglitz 7o
79.98		o.33			1 ?		Fröhner 72
81.95		o.22			1 ?		Fröhner 72
82.8	11o					o.5	Garg 64/71
83.8	8o					o.5	Garg 64/71
84.7					1		Stieglitz 7o
84.94		o.41			1 ?		Fröhner 72
86.33	33o			1.4	o		Fröhner 72
86.7	16o					o.5	Garg 64/71
86.8					o		Stieglitz 7o
87							Hockenbury 69
87.5	3oo				o		Bilpuch 61
87.6					1		Stieglitz 7o
87.89		o.64			1 ?		Fröhner 72
89.93		o.17			1 ?		Fröhner 72
91.6o		o.25			1 ?		Fröhner 72
93.3o					1		Stieglitz 7o
93.94		o.48					Fröhner 72
96.5					1		Stieglitz 7o
96.5	125o				o		Farrell 66 /7/
97.2o	1ooo			1.o	o		Fröhner 72
97.2							Hockenbury 69
97.7	1o7o					o.5	Garg 64/71
98.1	87o				o		Stieglitz 7o
99	1o67				o		Bilpuch 61
99.24		o.92			1 ?		Fröhner 72
1o1.9		o.1o			1 ?		Fröhner 72
1o6	84o				o		Farrell 66
1o7.8	61o				o		Stieglitz 7o
1o8	7oo			1.1	o		Fröhner 72
1o8	838				o		Bilpuch 61
1o9.5	175o					o.5	Garg 64/71
111.3		3.74			1		Stieglitz 7o
111.8		2.7			1 ?		Fröhner 72
12o.6		2.31			1		Stieglitz 7o
123.8	g=1 g=2				1		Stieglitz 7o
126.5	4o 23				> o		Farrell 66
129.7					1		Stieglitz 7o
136.5		4.31			1		Stieglitz 7o

Table III b) continued

Er /KeV/	Γ n /eV/ g=1	Γ n /eV/ g=2	$\frac{g\Gamma_n\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma\gamma$ /beV/	Γγ /eV/	l	J	Reference
138.5	7o	42				> o		Farrell 66
139.6			3.95			1		Stieglitz 7o
156	38o	229				> o		Farrell 66
156.4	44o					o		Stieglitz 7o
16o	18oo					o		Farrell 66
161	53oo						o,5	Garg 64/71
161	18oo					o		Bilpuch 61
162.1	125o					o		Stieglitz 7o
161.7	14oo				2.2	o		Fröhner 72
186	57oo						o.5	Garg 64/71
186.2	6ooo					o		Farrell 66
186.5	6ooo					o		Stieglitz 7o
187	57o8					o		Bilpuch 61
196	35oo						o.5	Garg 4/71
197	35oo					o		Farrell 66
198	31oo					o		Stieglitz 7o
199	6424					o		Bilpuch 61
2o6	11o	64				> o		Farrell 66
214	94	55				> o		Farrell 66
216								Garg 64
22o	98	57				> o		Farrell 66
229	2o8	12o				> o		Farrell 66
252	87o	47o				> o		Farrell 66
257.o	375o					o		Farrell 66
257.8	35oo					o		Stieglitz 7o
258								Garg 64
279.6	75o					o		Stieglitz 7o
282.5	62o	337				> o		Farrell 66
292.5	36o	198				> o		Farrell 66
3o6	5oo	275				> o		Farrell 66
3o6								Garg 64
316	32oo					o		Farrell 66
316.8	32oo					o		Stieglitz 7o
325	85oo					o		Farrell 66
326.3	68oo					o		Stieglitz 7o
338	525o					o		Farrell 66
339.5	75oo					o		Stieglitz 7o
346	25o					o		Farrell 66
357.2	1ooo					o		Farrell 66
358.5	1o76	575				> o		Farrell 66
375.5	4ooo					o		Farrell 66
378.5	22o	116				> o		Farrell 66
387.5	28o	15o				> o		Farrell 66
392	266	142				> o		Farrell 66
397	312	165				> o		Farrell 66
4o1.5	39o	2o5				> o		Farrell 66
412.3	75o					o		Farrell 66
421	2ooo					o		Farrell 66
426.5	5oo					o		Farrell 66
431.5	21o	12o				> o		Farrell 66

Table III b) continued

Er /KeV/	Γ_n /eV/ g=1	g=2	$\frac{g\Gamma_n\Gamma_\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma_\gamma$ /beV/	Γ_γ /eV/	l	J	Reference
436	1000					o		Farrell 66
446	3000					o		Farrell 66
453	1500					o		Farrell 66
462	1000					o		Farrell 66
473	500					o		Farrell 66
484.6	3750					o		Farrell 66
497.5	565	295				> o		Farrell 66
498	5000					o		Farrell 66
502.5	325	170				> o		Farrell 66
511.5		1000				> o		Farrell 66
513.5	2250					o		Farrell 66
520.3	5000					o		Farrell 66
525.5	3000					o		Farrell 66
533	500					o		Farrell 66
552.5	700	360				> o		Farrell 66
556.5	500					o		Farrell 66
566	260	130				> o		Farrell 66
580.3	250					o		Farrell 66
588.5	500					o		Farrell 66
594.8	2500					o		Farrell 66

Table III c) Resonance parameters for Ni-61 I= 3/2

Er /KeV/	$2g\,\Gamma_n$ /eV/	Γ'_n /eV/	$\frac{g\Gamma_n\,\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma\gamma$ /beV/	$\Gamma\gamma$ /eV/	l	J	Reference
1.354			o.24	478				Hockenbury 69 /24/
2.35								Hockenbury 69
3.14			o.o84	71				Hockenbury 69
3.3o			o.48	341				Hockenbury 69
6.47			o.35	145				Hockenbury 69
6.97	23							Good 65 /4/
7.12			o.78	285				Hockenbury 69
7.152		74			2,5	o	1	Fröhner 72 /22,32)
7.37	238							Good 65
7.53								Hockenbury 69
7.545		177			2.3	o	2	Fröhner 72
8.71			o.65	196				Hockenbury 69
8.745		6			2.6	o	2	Fröhner 7o
9.9o								Hockenbury 69
9.93			o.o9			1 ?		Fröhner 72
1o.18			o.19			1 ?		Fröhner 72
1o.2								Hockenbury 69
12.4	67.7							Good 65
12.6								Hockenbury 69
12.64	75				1.7	o	2	Fröhner 72
13.3	75.9							Good 65
13.43			o.31			1		Fröhner 72
13.63		61			1.6	o	2	Fröhner 72
13.7	13							Good 65
14.o								Hockenbury 69
14.o2		17			3.1	o	1	Fröhner 72
14.3								Hockenbury 69
14.45			o.3			1?		Fröhner 72
15.3								Hockenbury 69
15.38			o.17			1 ?		Fröhner 72
16.3	411							Good 65
16.7								Hockenbury 69
16.7		81o			2.2	o	1	Fröhner 72
16.8			o.14			1 ?		Fröhner 72
17.5	174							Good 65
17.8								Hockenbury 69
17.86		177			1.6	o	1	Fröhner 72
18.3	181							Good 65
18.87		69			o.9	o	2	Fröhner 72
19								Hockenbury 69
2o.25			o.o9			1 ?		Fröhner 72
2o.4								Hockenbury 69
2o.55			o.11			1 ?		Fröhner 72
21.4o			o.88			o ?		Fröhner 72
23.8	1oo							Good 65
24.12			o.36			1 ?		Fröhner 72
24.62		129			1.4	o	1	Fröhner 72
24.8			3.98	425				Hockenbury 69
25.12			o.25			1 ?		Fröhner 72
25.96			o.24			1 ?		Fröhner 72
26.45			o.18			1 ?		Fröhner 72
27.1o			o.2o			1 ?		Fröhner 72
27.65			o.4o			1 ?		Fröhner 72

Table III c) continued

Er /KeV/	$2g\Gamma_n$ /eV/	Γ_n /eV/	$\frac{g\Gamma_n\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma\gamma$ /beV/	$\Gamma\gamma$ /eV/	l	J	Reference
27.6			1.74	164				Hockenbury 69
28.2	236							Good 65
28.21		5.o			3.o	o	2	Fröhner 72
29.o								Hockenbury 69
29.11		4o9			2.4	o	1	Fröhner 72
3o.2	423							Good 65
3o.64		15				o	2	Fröhner 72
3o.8								Hockenbury 69
31.13		788				o	1	Fröhner 72
31.6	392							Good 65
31.7								Hockenbury 69
31.83		1o				o	2	Fröhner 72
32.7	12o							Good 65
32.7		22o				o	2	Fröhner 72
33.68		58			2.8	o	1	Fröhner 72
33.8	123							Good 65
33.8								Hockenbury 69
34.65						1 ?		Fröhner 72
36.o2						1 ?		Fröhner 72
36.o	294							Good 65
37.13		133			3.o	o	2	Fröhner 72
37.3								Hockenbury 69
39.77						1 ?		Fröhner 72
4o	243							Good 65
41.3								Hockenbury 69
41.34		176				o	1	Fröhner 72
42.2	133							Good 65
43.25		1o				o	2	Fröhner 72
43.61		3o				o	2	Fröhner 72
44	169							Good 65
45.49		66				o	1	Fröhner 72
46.1								Hockenbury 69
46.16		54						Fröhner 72
48.4	83							Good 65
5o.51		133				o	1	Fröhner 72
5o.7								Hockenbury 69
53.3		141				o	2	Fröhner 72
54.81		189				o	1	Fröhner 72
56.49		119				o	2	Fröhner 72
58.16		178				o	1	Fröhner 72
58.7								Hockenbury 69
64.o7		54				o	2	Fröhner 72
65.87		143o				o	2	Fröhner 72
68.77		11oo				o	2	Fröhner 72
7o.8								Hockenbury 69
89.6								Hockenbury 69

Table III d) Resonance parameters for Ni-62

Er /KeV/	g Γn /eV/	Γn /eV/ g=1	Γn /eV/ g=2	$\frac{g\Gamma_n\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma\gamma$ /beV/	Γγ /eV/	l	Reference
2.34								Hockenbury 69/24/
4.54		134o						Garg 64/71/23/
4.6						o.75		Hockenbury 69
12.879		31o					o	Beer 71 /25/
56.907	56						1	Beer 71
77.126		69.8					o	Beer 71
78.422	48						1	Beer 71
89.3		25o						Garg 64/71
93.5		225o					o	Farrell 66/7/
94.742		268o					o	Beer 71
95.5		162o						Garg 64/71
1o4.5		45oo					o	Farrell 66
1o4.5		385o						Garg 64/71
1o5.674		4884					o	Beer 71
137.5		113	7o				>o	Farrell 66
148.5		2oo						Garg 64/71
148.5		2oo					o	Farrell 66
149.31		136					o	Beer 71
188.21		92					o	Beer 71
189.5		125	75				>o	Farrell 66
214.65		194					o	Beer 71
216.5		175	1o3				>o	Farrell 66
229.5		725o					o	Farrell 66
229.5		618o					o	Beer 71
242.2		75o					o	Farrell 66
243.23		776					o	Beer 71
259.5		1o5	6o				>o	Farrell 66
272.5		315	175				>o	Farrell 66
28o.5		55oo					o	Farrell 66
281.o5		482o					o	Beer 71
286		15oo					o	Farrell 66
288		1ooo					o	Beer 71
297		19o	1o5				>o	Farrell 66
299.5		47o	26o				>o	Farrell 66
3o4		8oo					o	Farrell 66
315.5		225	125				>o	Farrell 66
319		356	197				>o	Farrell 66
323		56o	32o				>o	Farrell 66
327		55oo					o	Farrell 66
344.2		75oo					o	Farrell 66
352		267	145				>o	Farrell 66
356.2		2ooo					o	Farrell 66
364		187	1oo				>o	Farrell 66
374.5		25o					o	Farrell 66
382.5		125o					o	Farrell 66
388.5		45oo					o	Farrell 66
4o1.2		15oo					o	Farrell 66
4o3.3		4o35	19o				>o	Farrell 66
42o.3		8oo	413				>o	Farrell 66
423		15oo					o	Farrell 66
433		65oo					o	Farrell 66

Table III d) continued

Er /KeV/	gΓn /eV/	/EV/ g=1	Γn g=2	gΓnΓγ / Γ /eV/	σ_oΓγ /beV/	Γγ /eV/	l	Reference
444		350					o	Farrell 66
446.5							> o	Farrell 66
449.8		248	125				> o	Farrell 66
450		318	165				> o	Farrell 66
458.0		500					o	Farrell 66
461.8		540	280				> o	Farrell 66
475		1500					o	Farrell 66
480 ← 488.5		318 4000	165				> o	Farrell 66
493.5		890	456				> o	Farrell 66
498		1500					o	Farrell 66
508.5		500					o	Farrell 66
515.5		140	75				> o	Farrell 66
522		380	200				> o	Farrell 66
529		1725	925				> o	Farrell 66
535.5		1600	830				> o	Farrell 66
539		2000					o	Farrell 66
554.0		655	340				> o	Farrell 66
568.5		825	430				> o	Farrell 66
571.8		4000					o	Farrell 66
581		500					o	Farrell 66
583.5		10000					o	Farrell 66
590.5		2000					o	Farrell 66
599.5		810	420				> o	Farrell 66

Table III e) Resonance parameters for Ni- 64

Er /KeV/	$g\Gamma_n$ /eV/	Γ_n /eV/ g=1	g=2	$\frac{g\Gamma_n\Gamma_\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma_\gamma$ /beV/	Γ_γ /eV/	l	Reference
9.52				1.73	473			Hockenbury 69/24/
13.8		3ooo						Good(quoted in/7/)
14.3		29oo					o	Beer 71 /25/
26								Hockenbury 69
33.2		95oo						Good (quoted in/7/
33.7		97oo						Beer 71
39.2								Hockenbury 69
46.1								Hockenbury 69
53.9								Hockenbury 69
64								Hockenbury 69
83.4								Hockenbury 69
1o5		115	65				>o	Farrell 66/7/
1o6,5	11o						1	Beer 71
128.8		17oo					o	Farrell 66 /7/
129.3		131o					o	Beer 71
141.5		14o	8o				>o	Farrell 66
142	17o						1	Beer 71
148.8		95					o	Beer 71
154.9		375o					o	Beer 71
154.5		5ooo					o	Farrell 66
163		3oo					o	Farrell 66
163.2		14o					o	Beer 71
177.5		5oo					o	Farrell 66
177.6		51o					o	Beer 71
191		1o5	57				>o	Farrell 66
191.5	16o						1	Beer 71
2o5.3		95					o	Beer 71
213.7		15o	8o				>o	Farrell 66
214.7	82						1	Beer 71
219.8		3o					o	Beer 71
226.9		12o					o	Beer 71
231		4ooo					o	Farrell 66
231.9		377o					o	Beer 71
235.7		395	2o5				>o	Farrell 66
237.9	32o						1	Beer 71
254		57o	3o4				>o	Farrell 66
255.7	17o						1	Beer 71
268		3ooo					o	Farrell 66
269.7		221o					o	Beer 71
274		31o	165				>o	Farrell 66
283		35o					o	Beer 71
289		1o5	55				>o	Farrell 66
298		1ooo					o	Farrell 66
3o8.5		15oo					o	Farrell 66
32o							>o	Farrell 66
326,5		585	3o3				>o	Farrell 66
333		25o					o	Farrell 66
334							>o	Farrell 66
34o.2		5oo					o	Farrell 66
352							>o	Farrell 66
36o.3		715	37o				>o	Farrell 66
365			9oo				>o	Farrell 66
368							>o	Farrell 66

Table III e) continued

Er /KeV/	$g\Gamma_n$ /eV/	Γ_n /eV/ g=1	Γ_n /eV/ g=2	$\frac{g\Gamma_n\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma\gamma$ /beV/	$\Gamma\gamma$ /eV/	l	Reference
371.5			600				>o	Farrell 66
376		270	140				>o	Farrell 66
383			656				>o	Farrell 66
389		6000					o	Farrell 66
392.5		230	120				>o	Farrell 66
395.5		810	410				>o	Farrell 66
407			1000				>o	Farrell 66
414		750	384				>o	Farrell 66
420.8		8000					o	Farrell 66
455.5		750					>o	Farrell 66
459.5			500				>o	Farrell 66
466.5		1000					>o	Farrell 66
470		530	270				>o	Farrell 66
479		1000					>o	Farrell 66
483		5000					o	Farrell 66
487.8		430	220				>o	Farrell 66
499.5		530	270				>o	Farrell 66
503		760	386				>o	Farrell 66
519		475	240				>o	Farrell 66
523		1000					o	Farrell 66
529.3		750					o	Farrell 66
536.5		10000					o	Farrell 66
541.5		1700	870				>o	Farrell 66
552.0		2000					o	Farrell 66
565		890	456				>o	Farrell 66
576		4000					o	Farrell 66
583		300					o	Farrell 66

Table IV) Resonance parameters for Na-23 , I = 3/2

Er /KeV/	Γ_n /eV/	g Γn /eV/	$\Gamma\gamma$ /eV/	$\frac{g\Gamma n\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma\gamma$ /beV/	l	J	Reference
2.8o	42o	158				o	1	Good 58 /95/
2.85	4o5	152				o	1	Lynn 58 /94/
2.85			o.6					Block 66/92/
2.85			o.61				1	Hockenbury 69 /24/
			o.45					Hockenbury 69 corr./98/
2.85			o.47			o	1	Hockenbury 7o/98/
2.85			o.35			o	1	Friesenhahn 68/97/
2.851	38o	238				o	2	Garg 65/96/
2.86	424	159	o.6			o	1	Moxon 66/89/
2.95	22o	138				o	2	Hibdon 6o/88/
7.53				o.oo49	1.68	1		Hockenbury 69
7.6								Block 66
35.o				o.394	29.3			Hockenbury 69
35.39				$2\pi^2\lambda_{o2}^2 g\Gamma_n$:60eVb				Ribon 66 /91/
35.5								Block 66
36.o				21eVb/$2\pi^2\lambda_o^2$		>2		Le Rigoleur 66/9o
52.2	7oo assumed		2.6g=3/8 1.58g=5/8 1.12g=7/8			1		Hockenbury 69
53.4								Block 66
54.o	12oo	75o				1	2	Moxon 66
54.o				21eVb/$2\pi^2\lambda_o^2$				Le Rigoleur 66
54.1	75o	65o				1	3	Hibdon 6o
55.o	2oo					o	2	Hibdon 6o
61.5	3oo					1	o	Hibdon 6o
63.6	4oo					1	1	Hibdon 6o
66.8	4oo					1	1	Hibdon 6o
72.5	3oo					1	2	Hibdon 6o
75.7	55o					1	o	Hibdon 6o
77.6	5oo					1	o	Hibdon 6o
79.9	6oo					1	o	Hibdon 6o
81.5	7oo					1	o	Hibdon 6o
83.9	65o					1	o	Hibdon 6o
85.3	35o					1	o	Hibdon 6o
86.4	3oo					1	o	Hibdon 6o
88.4	4oo					1	o	Hibdon 6o
91.3	45o					1	1	Hibdon 6o
93.o	5oo					o	1	Hibdon 6o
96.5	1ooo					1	o	Hibdon 6o
98.6	45o					1	1	Hibdon 6o
1oo.9	35o					1	1	Hibdon 6o
1o3.2	5oo					1	o	Hibdon 6o
1o4.3	55o					1	o	Hibdon 6o
1o5.9	35o					1	1	Hibdon 6o
1o7.4	45o					o	1	Hibdon 6o
111.5	55o					1	1	Hibdon 6o
113.5	6oo					1	o	Hibdon 6o
114.7				1.5	33.7			Hockenbury 69
116.7	5oo					1	1	Hibdon 6o
117.6				$2\pi^2\lambda_o^2 g\Gamma_n$: 430eVb				Ribon 66

Table IV (continued)

Er /KeV/	Γ_n /KeV/	l	J	Reference
297.o	4.o	o	1	Stelson 52
298.o	2.o	2	o	Hibdon 6o
298.4	1.9	o	2	Nebe 7o/99/
3oo.o				Block 66
3o2.5	2.5	o	2	Hibdon 6o
3o6.5	1.6	2	o	Hibdon 6o
311.8	1.5	2	1	Hibdon 6o
316.5	o.9	3(2)	2	Hibdon 6o
321.o	o.9	3(2)	1	Hibdon 6o
324.o	1.3	2	1	Hibdon 6o
326.8	o.9	3(2)	1	Hibdon 6o
33o.8	2.o	2	1	Hibdon 6o
334.2	1.o	3(2)	1	Hibdon 6o
338.3	1.7	2	1	Hibdon 6o
34o	4.o			Stelson 52
343.6	1.o	3(2)	2	Hibdon 6o
346.o	o.75	3(2)	1	Hibdon 6o
352.6	1.6	1	1	Hibdon 6o
355.9	1.5	1	1	Hibdon 6o
359.7	o.9	2	2	Hibdon 6o
362.o	1.o	2	2	Hibdon 6o
363.8	o.8	2	2	Hibdon 6o
368.o	1.6	1	1	Hibdon 6o
372.2	o.9	1	2	Hibdon 6o
375.o	1.5	1	2	Hibdon 6o
378.9	1.6	1	2	Hibdon 6o
382.7	o.9	3(2)	3	Hibdon 6o
384.7	1.5	1	2	Hibdon 6o
388.8	1.4	3(2)	3	Hibdon 6o
391.2	o.7	3(2)	3	Hibdon 6o
393.6	o.8	3(2)	3	Hibdon 6o
393.8	25.8	1	1	Nebe 7o
396	23.o	1	1	Stelson 52
397.9	1.3	2	4	Hibdon 6o
4oo.5	1.4	2	4	Hibdon 6o
4o3.o	1.1	2(3)	4	Hibdon 6o
4o5.8	3.o	o	2	Hibdon 6o
411.2	1.5	2	2	Hibdon 6o
414.6	o.9	3(2)	3	Hibdon 6o
417.o	1.2	3(2)	2	Hibdon 6o
419.1	o.9	3(2)	3	Hibdon 6o
421.6	1.9	o	2	Hibdon 6o
426.5	o.9	3(2)	1	Hibdon 6o
428.4	o.6	3	2	Hibdon 6o
43o.4	o.7	3	2	Hibdon 6o
431.2	7.8	1	o	Nebe 7o
432.2	o.9	3	2	Hibdon 6o
436.5	o.7	3	3	Hibdon 6o
439.o	1.1	3(2)	3	Hibdon 6o
443.o	1.3	2(3)	3	Hibdon 6o
446.2	1.2	3(2)	4	Hibdon 6o
448.4	5.7	2	2	Nebe 7o
449.6	1.9	2(3)	4	Hibdon 6o
451	9	1(2)	2	Stelson 52
451.2	3.7	o	2	Hibdon 6o
456.6	o.8	3(2)	2	Hibdon 6o
459.7	o.6	3(2)	2	Hibdon 6o
463.2	1.1	2(3)	2	Hibdon 6o
465.7	o.7	o	2	Hibdon 6o
471.5	o.7	3(2)	2	Hibdon 6o
476.5	1.3	2	2	Hibdon 6o
481.3	o.75	3(2)	2	Hibdon 6o
487.2	1.1	3	2	Hibdon 6o
493.9	o.75	3	2	Hibdon 6o
5o8.8				Nebe 7o
511.o	1.o	3	2	Hibdon 6o
53o.3	o.75	3	3	Hibdon 6o
532.7	1.o	3	3	Hibdon 6o
535.4	1.1	3	3	Hibdon 6o
536.6	35.3	o	1	Nebe 7o
538.8	4.5	o	2	Hibdon 6o
542.o	39	(o)	(1)	Stelson 52
545.o	o.6	3	2	Hibdon 6o
549.9	1.4	2	2	Hibdon 6o
552.8	1.4	2	2	Hibdon 6o
557.o	o.8	3(2)	3	Hibdon 6o
561.2	1.3	2(3)	3	Hibdon 6o
564.1				Nebe 7o
564.8	1.3	2(3)	3	Hibdon 6o
568.3	o.6	3(2)	3	Hibdon 6o
57o.4	o.9	3(2)	3	Hibdon 6o
575.3	1.5	2	3	Hibdon 6o
578.7	2.o	2	2	Hibdon 6o
582.9	1.6	2(3)	3	Hibdon 6o
586.6	1.6	2(3)	3	Hibdon 6o
59o.o	1.6	2	1	Hibdon 6o
592.8	1.2	3	4	Hibdon 6o
595.3	1.3	3	4	Hibdon 6o
597.8	25.8	(1)	1	Nebe 7o
599.8				Nebe 7o
6o1.o	3.5	2	4	Hibdon 6o
6o2.o	6		(1)	Stelson
6o5.o	1.7	3	3	Hibdon 6o
6o8.3	1.o	3	4	Hibdon 6o
611.3	1.7	3	3	Hibdon 6o
615.2	1.1	3	4	Hibdon 6o
618.8	1.7	3	3	Hibdon 6o
621.o	o.8	3	4	Hibdon 6o
623.o	o.8	3	4	Hibdon 6o
626.2	2.7	2	3	Hibdon 6o
627.o				Nebe 7o
629.8	1.8	2	3	Hibdon 6o
632.9	1.o	3	2	Hibdon 6o
634.8	1.2	3	2	Hibdon 6o
638.o	2.2	2	3	Hibdon 6o
642.2	1.7	3	2	Hibdon 6o
645.1	1.4	3	2	Hibdon 6o
647.9	1.2	3	3	Hibdon 6o
651.5	1.9	3	3	Hibdon 6o

Table IV (continued)

Er /KeV/	Γ_n /eV/	$g\Gamma n$ /eV/	$\Gamma\gamma$ /eV/	$\frac{g\Gamma n\Gamma\gamma}{\Gamma}$ /eV/	$\sigma_o\Gamma\gamma$ /beV/	l	J	Reference
117.8								Block 66
118.4	600					1	1	Hibdon 60
120.2	500					0	1	Hibdon 60
124	900					1	0	Hibdon 60
127.2	500					1	1	Hibdon 60
129.2	700					1	0	Hibdon 60
129.5				0.29	5.74			Hockenbury 69
131.8	1000					1	0	Hibdon 60
134.9	700					1	1	Hibdon 60
137.5	400					2	1	Hibdon 60
138.9	400					2	1	Hibdon 60
139.1				0.71	13.2			Hockenbury 69
141.5	700					1	1	Hibdon 60
144								Block 66
144.2	500					2	1	Hibdon 60
146	500					2	1	Hibdon 60
147.6	400					1	0	Hibdon 60
149.3	750					1	0	Hibdon 60
150.7	800					1	0	Hibdon 60
153.2	400					2	1	Hibdon 60
154.9	450					2	1	Hibdon 60
156.6	450					2	1	Hibdon 60
160.8	2000					1	0	Hibdon 60
167.3	1700					1	0	Hibdon 60
171.8	2200					1	0	Hibdon 60
175.7	1900					1	0	Hibdon 60
178.4	1700					1	0	Hibdon 60
182.6	2000					1	0	Hibdon 60
188	1600					1	1	Hibdon 60
193.0	1200					2(1)	1	Hibdon 60
196.7	1100					2(1)	1	Hibdon 60
199.5	700					2	2	Hibdon 60
207.7	1800					1	3	Hibdon 60
204	5000					1	1	Stelson 52/87/
205.2	3600					0	1	Hibdon 60
213.7	1300					1(2)	2	Hibdon 60
217	~14000					1	0	Stelson 52
218.2	1200					1(2)	2	Hibdon 60
224.0	1700					1(2)	1	Hibdon 60
227.7	1700					1(2)	1	Hibdon 60
231.9	900					0	2	Hibdon 60
240								Block 66
242.0	6000					1	2	Hibdon 60
243	7000					1	1(2)	Stelson 52
246.3	3000					0	1	Hibdon 60
255.0	1300					2	2	Hibdon 60
260.5	1700					2(1)	1	Hibdon 60
264.7	900					2	1	Hibdon 60
268.5	1100					2	2	Hibdon 60
272.8	1100					2	1	Hibdon 60
278.5	1300					2	1	Hibdon 60
287.0	1300					2	1	Hibdon 60
290.7	900					2	2	Hibdon 60
294.7	1300					2	1	Hibdon 60

Table IV (continued)

Er /KeV/	Γ_n /KeV/	l	J	Reference
655.6	2.3	2	3	Hibdon 6o
658.1	1.6	3	3	Hibdon 6o
661.4	2.3	2	3	Hibdon 6o
665.8	2.o	2	4	Hibdon 6o
669.3	2.4	2	2	Hibdon 6o
67o				Block 66
672.o	1.8	2	3	Hibdon 6o
674.1	2.8	2	2	Hibdon 6o
676.6	2.6	2	3	Hibdon 6o
679.7	2.1	2	2	Hibdon 6o
682.4	1.7	3	4	Hibdon 6o
683.4				Nebe 7o
685.6	1.9	4	6	Hibdon 6o
688.8	1.7	4	6	Hibdon 6o
692.4	2.6	4	5	Hibdon 6o
696.5	3.4	2	4	Hibdon 6o
697.2	6o	(2)	(4)	Nebe 7o
7oo.3	4.1	3	5	Hibdon 6o
7o3.3	2.5	2	4	Hibdon 6o
7o7.3	1.8	4	6	Hibdon 6o
7o9.5	1.6	5	6	Hibdon 6o
71o	72		(5)	Stelson 52
712.1	2.4	4	6	Hibdon 6o
716.o	3.o	5	7	Hibdon 6o
719.3	2.3	3	4	Hibdon 6o
721.6	2.2	5	6	Hibdon 6o
724.8	2.7	4	6	Hibdon 6o
726.6	45	(1)	(3)	Nebe 7o
727.9	2.7	3	4	Hibdon 6o
731.o	2.1	4	6	Hibdon 6o
734.o	1.7	5	6	Hibdon 6o
736.8	2.5	2	4	Hibdon 6o
74o.5	3.o	3	5	Hibdon 6o
744.2	2.5	2	2	Hibdon 6o
747.o	2.5	2	3	Hibdon 6o
748.3				Nebe 7o
749.8	2.6	2	2	Hibdon 6o
752.4	2.2	2	1	Hibdon 6o
756.3	3.4	2	3	Hibdon 6o
759.8	1.9	2	1	Hibdon 6o
763.4	2.o	2	3	Hibdon 6o
766.4				Nebe 7o
766.7	1.8	4	5	Hibdon 6o
768.6	1.9	2	3	Hibdon 6o
773.3	3.2	3	5	Hibdon 6o
776.o	1.3	2	1	Hibdon 6o
778.2	2.9	3	5	Hibdon 6o
78o.5	43.6	(2)	(4)	Nebe 7o
782.4	3.6	2	3	Hibdon 6o
784.o	3.8		2(3)	Stelson 52
786.3	2.6	4	6	Hibdon 6o
789.2	2.1	2	1	Hibdon 6o
792.4	2.9	3	5	Hibdon 6o
795.8	2.1	4	5	Hibdon 6o
798.7	2.4	3	5	Hibdon 6o
8o1.o	2.o	2	3	Hibdon 6o
8o2.7	2.1	2	1	Hibdon 6o
8o6.9	3.4	2	4	Hibdon 6o
8o9.o	2.2	2	1	Hibdon 6o
812.6	4.o	2	4	Hibdon 6o
818.o	2.o	3	2	Hibdon 6o
821.o	2.o	3	4	Hibdon 6o
824.o	2.o	3	3	Hibdon 6o
826.4	2.2	3	2	Hibdon 6o
83o.1	2.1	3	4	Hibdon 6o
832.5	1.5	3	3	Hibdon 6o
835.o	2.3	2	2	Hibdon 6o
836.8	1.5	3	2	Hibdon 6o
841.2	2.2	3	3	Hibdon 6o
843.8	1.7	3	4	Hibdon 6o
847.7	2.3	3	3	Hibdon 6o
852.o	2.8	2	2	Hibdon 6o
854.5	2.6	2	1	Hibdon 6o
857.5	3.o	2	2	Hibdon 6o
911.2	4o.1	(2)	(3)	Nebe 7o
914	36		(3)	Stelson 57
968				Nebe 7o
985.1	27.2	(2)	(1)	Nebe 7o
988.o	24		(1)	Stelson 52