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Neutron Cross Section Measurements for Nuclear Structure and Nuclear Energy

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I. Introduction

Recently there have been remarkable improvements in the techniques of neutron physics (1), unnoticed by many nuclear physicists. Measurements of neutron cross sections can now make significant contributions to our knowledge of the structure of the nucleus. However, in addition to contributing to our understanding of the structure of the nucleus, neutron cross section measurements also contribute to the further development of nuclear energy. Many physicists are not aware that our knowledge of neutron cross sections is not adequate for the calculation of the properties of fast reactors. Yiftah, Okrent, and Moldaur have recently reviewed the situation in their book, Fast Reactor Cross Sections (2) and state the following in their conclusion: "Available microscopic neutron cross section data--supplemented by estimates based on nuclear theory, consistently predict smaller critical masses than are observed experimentally. These findings reveal that few cross sections are sufficiently well measured (for the purposes of fast reactor calculations) without experimental gaps or contradictions."

II. Recent Developments in the Neutron Cross Section Field

The recent developments in the fast time-of-flight neutron spectroscopy (3) place a powerful tool in the hands of experimentalists who want to contribute both to our knowledge of the properties of nuclear energy levels and to the development of nuclear energy. Slow neutron time-of-flight techniques have been used for many years, but the extension of these techniques to higher energies has only recently been developed. The delay in this development was primarily technical; the flight times to be measured for fast neutrons are in the range of 10^{-7} and 10^{-9} sec, a range which has become accessible because of the developments in photo-multipliers, scintillators and amplifiers. The effective yield of pulse neutrons in charge particle accelerators has recently been increased by improvements in ion sources (4) and by using bunching magnets (3). Consequently, effective source intensities have increased by several orders of magnitude in the last few years. Experiments which previously were impossible because of intensity reasans are now done with comparative ease. The recent work on the inelastic scattering of neutrons from tungsten (3) and other elements by A.B. Smith of Argonne National Laboratory illustrates how potent a tool the fast neutron time-of-flight technique is for unravelling the structure of the nucleus. The results given by L. Cranberg of the Los Alamos Scientific Laboratory (3) illustrate the detailed comparison one can make between the experimental results and the calculations using the optical model. It is quite clear that with the improved techniques there is a vast opportunity for exploitation of the field both for contributions to the theory of the structure of the nucleus and to the nuclear energy program.

Inelastic neutron cross sections are required for two aspects of the nuclear energy program; one is in the shielding and the other in the moderation of neutrons. To calculate the effectiveness of a shield, one must know the number and energy distribution of the gamma rays emitted when a neutron is inelastically scattered. The necessity of a knowledge of the inelastic neutron cross section for determining the moderation of neutrons in fast reactors (5) has long been recognized but only recently become significant because of the proposed use of fast reactors for power production. Simple diffusion and slowing down theory as normally applied for determining the properties of thermal and epithermal reactors usually ignore the inelastic scattering of neutrons. The moderating material is assumed to be a gas of the mass of the moderator, and the only collisions allowed are elastic collisions. However, recent theoretical calculations and results on experimental fast breeder reactors (6) have shown that the reactor designer must have extensive data on neutron inelastic scattering cross sections. It is necessary therefore to determine the inelastic scattering cross section of the fissile and fertile materials as well as the materials of reactor construction.

If breeder reactors are to be substantially improved, the resonance parameters of the fissile, fertile, and reactor construction materials must also be known. A good example of why the resonance parameters, the average values of the resonance parameters, and the fluctuation about the average are needed for fast reactor calculations, can easily be illustrated by the case of a fast reactor which uses Pu^{239} as a fuel and has a U^{238} blanket. The temperature coefficient of this type of fast reactor is going to depend on the details of the resonance structure of the U^{238} and the Pu^{239}. The temperature coefficient of a reactor, if it is to be safe, should preferrably be negative.

The reactivity temperature coefficient of a fast breeder reactor depends on the Doppler broadening of the neutron resonances of the material in the reactor. Resonance levels which capture neutrons will give a negative coefficient because the level broadens as the temperature increases, thereby increasing the energy range over which absorbtion is effective. The probability of removing a neutron is thereby increased and the reactivity decreases. However, for a resonance which leads to fission the doppler broadening leads to an increase in the probability of fission and an increase in the number of neutrons, thus increasing the reactivity. Unfortunately the resonances in fissile materials are not purely fission or purely capture, but a complex mixture of both. In the KeV region the resonances in U^{238} capture neutrons giving a negative Doppler Reactivity coefficient, and the resonances in Pu^{239} lead predominantly to fission giving a positive Doppler coefficient, although the magnitude of the Doppler coefficient of Pu^{239} is very uncertain; and it may even change sign as the energy increases. Obviously the Doppler temperature coefficient of a system which mixes U^{238} and Plutonium will depend on the fraction of Pu to U^{238} present and the manner in which the resonance cross section changes with the temperature. Doppler coefficient changes for fast reactors have been developed by several investigations (7) using different assumptions and approximations. The reader is referred to the report by Nicholson (7) for a review of the situation.

The resonance integral of Th^{232} also serves as a very important illustration of the need for resonance parameters. The resonance integral tells how effective a substance is in abosrbing neutrons in the energy region where absorption occurs. The resonance integral of thorium as determined by integrating over the resonance parameters should agree with the measurement of this quantity in a reactor. Unfortunately the quantities do not agree; recent measurements of the capture widths of thorium have shown that the average values of the capture gamma ray width published in BNL 325 were probably too large, and the decreased average value of Γ for thorium brings the resonance integral calculated from the resonance parameter into closer agreement with the measured resonance integral.

An excellent example of how knowledge of a neutron cross section can effect the determination of the economics of a breeder reactor is the capture cross section of Pa^{233}. In a breeder reactor which uses thorium as the fertile material and produces U^{233}. In a thermal breeder the reactor core is usually surrounded with a blanket of thorium. Neutrons are captured by natural Th^{232} to form Th^{233}. The Th^{233} decays to Pa^{233} with a half life of 23.5 min, and Pa^{233} decays to U^{233} with a half life of 27.4 days. U^{233} is fissionable with low energy neutrons. The capture cross section of Pa^{233} is critical for determining the economics of the breeding process, because if Pa^{233} captures a neutron to form Pa^{234}, the Pa^{234} decays to U^{234}, which is not a fissile isotope. Therefore, if the capture cross section of Pa^{233} is small, most of the isotope will decay to U^{233}, and the breeding process will be efficient. However, if the capture cross section is large, then U^{234} will be produced, and the breeding process will not be as efficient.

The capture cross section of Pa^{233} is extremely difficult to measure because of its short life time and consequent strong radioactivity. The isotope must be produced in a reactor and rapidly separated from the Th fission products and other contaminants. The sample is then placed in a special neutron velocity spectrometer which is elaborately shielded and remotely operated. In spite of the great difficulties in the determination of this cross section, several measurements have been made and a great deal of effort is going into improving its precision. There are many other examples of the importance of the neutron cross section of those isotopes which are built up as a result of neutron capture, but the Pa^{233} case is probably the simplest and easiest case to use to demonstrate the principles. Several examples of the cross sections desired for this purpose are given in Table 5.

The problems involved in neutron cross section measurements are many and require the highest type of scientific endeavor if the results are to be useful. Unfortunately, the neutron cross section compilations like BNL 325 lead the casual observer to believe that most of the data required for reactor calculations are available. However, this is not the case. Dr. Norman Francis of K.A.P.L. (8), who has recently completed a study of the cross section data available for the design of a fast breeder, estimated that not more than 50% of the information required was available in the compilation. The remainder has to be inserted, by using nuclear theories of doubtful validity.

There are still many cross sections of prime importance to the design of reactors which have not been measured and many more which have been measured in the past but not to sufficient accuracy. Today there are five broad categories of neutron cross sections for which the existing data are inadequate. These are:

Differential cross sections for elastic scattering
Nonelastic neutron processes
Capture cross sections
Resonance parameter and radiation capture cross sections
Cross sections of fissile and neighboring nuclei.

Let us examine in more detail all of the neutron cross sections which are measured and see what further information is desired for the design of reactors.

III. Cross Sections Required for Reactor Calculations

Total Cross Sections

The easiest cross sections to measure and the ones for which data on most elements are available are the total cross section. There are a few specific cases where the total cross sections are not known in the energy range of interest for the peaceful uses of nuclear energy. However, generally these total cross sections are either relatively unimportant or are known to sufficient accuracy for reactor calculations. An examination of the latest edition of the neutron cross section compilation BNL 325, illustrates that most of the necessary data on total cross sections are available.

Differential Cross Sections

The next most complicated cross sections to measure are the total elastic scattering cross section and the differential elastic scattering cross section, which we will group together, because the total elastic scattering cross section is now usually determined by measuring the differential elastic scattering cross section and integrating over angles. Neutron elastic scattering cross sections have been measured for many years, and one might think that there would be adequate data available on all isotopes that are of interest to the nuclear energy program. This is not the case. The reactor designers would like to have the elastic scattering cross sections as a function of angle and energy for Li^6, Li^7, Be, B, C, N, O, Si, Ca, V, Fe, Ni, Th, U^{235}, U^{238}, Pu^{239}. It is true that the elastic scattering cross section has been measured (for limited energy regions) for many of these isotopes, and in general the experimental data is well-fitted by theoretical calculated cross-sections using the optical model of Perey and Buck (9). However, the data required are not available over the total energy region for which it is necessary. Table 1 lists several of the elastic cross sections which would be useful for reactor designs, together with the energy region over which these cross sections are desired. It states the accuracy required where it can be stated and gives some references to recent measurements.

Our knowledge of elastic scattering cross sections may not be as inadequate as one might suspect from examining the existing experimental data. Recent improvements in the theory of nuclear structure have allowed some of the elastic scattering cross sections to be calculated above 5 MeV for intermediate and heavy nuclei. It may be possible to calculate most of the elastic scattering cross sections required for nuclear reactor design from the optical model, non-local potential of Perey and Buck (9). The computer program they have developed for calculating the elastic scattering cross sections has been used to determine the differential elastic scattering cross sections for many isotopes. The results calculated show remarkable agreement with the experimental results for a limited energy region and mass number, giving a possible indication that the theory can be extended to lighter nuclei and lower energies.

Non-Elastic Neutron Cross Sections

The situation for non-elastic scattering of neutrons is quite different from that for elastic scattering. Here the data are entirely inadequate and the theory is not sufficiently developed to yield calculations of much value. Some success has been achieved in calculating non-elastic scattering at high energy for heavy nuclei. It is quite clear, however, that the nuclear models cannot be used successfully for calculating inelastic neutron scattering cross sections for low energies or for light and intermediate weight nuclei. The parameters of the theory, which give good results for differential elastic scattering, have been used to calculate the inelastic scattering and the results disagree with the experimental results (10). The disagreement varies from a factor of two or three for a light element like Mg at an energy of 2 to 3 MeV to about 20% for a heavy element like tungsten in the same energy region. Examples of the non-elastic processes for which information is required for reactor design are the non-elastic cross section as a function of the energy of the incident neutron, the energy spectra of the emitted gamma ray, and the angular distribution of the gamma rays with respect to the direction of the incident neutron for N, O, Al, Si, Ca, etc. Table 2 contains a list of those non-elastic cross sections which would be useful in reactor calculations, together with the energy range over which these cross sections are desired, and the accuracy required, where it can be stated. It is clear that the measurement of non-elastic and inelastic neutron cross sections can contribute both to the future development of nuclear theory as well as to an improvement in the technology of nuclear reactors.

Capture Cross Sections

Until recently the situation in the measurement of radiative capture cross sections has been very poor. The Au^{197} capture cross section serves as a standard. During the past several years the difference, among various laboratories, in experimental results on the gold capture cross section has been between 30 and 50%. The discrepancies lay far outside the experimental error, and the source of the discrepancy has not been determined. However, recent measurements have been more consistent and offer hope that the recently developed techniques, i.e., the large scintillation tanks used by Diven (11) and Desaussure (12), will be better than those used in the past. The capture cross section in the KeV region, extrapolated from the results of resonance parameter measurements, also does not agree with the direct measurement of the capture cross section. However, the theoretical extrapolation from the eV energy region to the KeV energy region requires several assumptions of doubtful validity and is probably as uncertain as the experimental results.

To calculate many of the properties of the reactors, it is extremely important, both from the point of view of neutron economy and radiation damage, to have the capture cross sections of the materials of which the reactor is constructed. For example, it would be desirable to know the capture cross sections of the potassium, calcium, vanadium, chromium, manganese, iron, nickel, mercury, lead, tungsten, and bismuth in the energy range from 0 to 2 MeV. However, it is improbable that these will be known very well over this whole energy range.

Table 3 lists the capture cross sections which would be desired for reactor design, the energy range over which these are desired, the accuracy required and some references to recent work in this field.

Resonance Parameter

Unfortunately the resonance parameters of individual neutron resonance levels cannot be calculated from any theory, and there is little hope that this calculation will ever be possible. The parameter must be determined experimentally. Due to the enormous improvements in the neutron velocity spectrometers (13), there are a large number of resonance parameters known. Table 4, however, gives the isotopes for which resonance parameters and capture cross sections are desired, the energy range, and the accuracy required for the solution of reactor problems.

Data on Fissile and Neighboring Nuclei

During the last few years the reactor designers have required more and more precise data on the fissile materials. More accurate values of $\sigma_{n,f}(E)$, $\gamma(E)$, $\eta(E)$, are desired. All of these quantities are very difficult to measure, and the precisions required difficult to achieve. Moreover, serious technical problems must be solved before many of these data can be obtained. For example, one method of measuring the absolute value of the fission cross section involves placing a foil containing the fissile material in a neutron beam and counting the fission events. This measurement requires a determination of the absolute number of atoms of the fissile material on the foil which is to be used for the measurements, an absolute measurement of the energy distribution of the neutron flux incident on the foil, and a precise determination of the efficiency of the counter which is used to measure the fission events. The relative importance of the problems varies with neutron energy.

Since the range of the fission fragments is only a few milligrams per cm^2 in any material, the deposits of the fissionable material must be very thin and therefore the quantity of material which must be determined to a high precision is very small. Another problem results from the fact that the fissile isotopes are chemically in the second rare earth group and consequently the salts are not stociometric compounds. Therefore the exact chemical composition of the material deposited on the foil must be determined. The fissionable material will penetrate the foil to some extent, and the range of the fission fragments in the salt is different than the range of the fission fragments in the foil; thus making the efficiency of the fission counter as well as the determination of the number of atoms difficult. A determination of an absolute neutron flux to better than one percent is a formidable job in itself, because the standard cross sections used for the determination of neutron fluxes are not determined to much better than 1%. In addition, one must develop better methods of determining the number of boron atoms in a given compound before the neutron flux can be determined to better than 1/2%.

Probably the most difficult part of determining the absolute value of the fission cross section is the determination of the number of atoms of the fissionable material on a plate. The short range of the fission fragments requires that the foil be thin, and therefore the number of fission events is small for the intensity of neutron beams currently available from nuclear reactors. The range of the fission fragments is not sufficiently well known to calculate the absolute value of the efficiency, and the measurements are not precise enough to improve the accuracy of the results by a factor of two better than previous measurements. Other methods have been used for the absolute determination of the fission cross section, but there are difficulties inherent in the other method which have not been completely resolved. The papers by Safford and Melkonian (14), and by Sapalaklu (15) illustrate in more detail some of the problems which must be considered and painstakingly investigated in the measurement of fission cross sections.

The cross sections and the other fission parameters of the fissile nuclei, although very difficult to measure, are extremely important from the point of view of the economics of nuclear energy. The highest type of scientific endeavor is required for these cross section measurements,since extremely good precision is required. In many cases precisions higher than the precision of the best nuclear cross sections measurements which have been made to date are demanded. A review of the thermal parameters for U^{233}(15), U^{235}(16), has been published recently. In general one can say that the situation is not satisfactory on any of these isotopes. Most is known about U^{235}. The information about U^{233} is not as well known,and the data on PU^{239} is poorest, because of its high specific alpha activity and its poor mechanical and chemical properties. It would be highly desirable if dedicated physicists who wanted to make a real contribution to the economics of the nuclear energy program would attempt further measurements on the fissile isotopes.

Some examples of measurements desired on the fissile nuclei are the absolute fission cross section of U^{233}, U^{235}, PU^{239}, PU^{241} at the standard energy of 0.0253 eV. Measurements of E^{ta} and the scattering cross section at the standard energy are also required to high precision. Any efforts to improve the accuracy of this data would be welcomed. Table 5 gives some examples of the cross sections and parameters of the fissile isotopes, the energy range for which these measurements are desired, the accuracy required, and some references to recent results.

Summarizing the state of neutron cross section measurements for the reactor design at the present time, we find that there are a large number of cross sections which are desired. The most recently developed theories of neutron interactions with nuclei can be of some help in determining the cross sections in energy ranges where they have not been measured, but the theories are of limited use, because they have not been developed sufficiently to calculate the results immediately. Even though the theory is finally developed as far as it can be within the framework of present capabilities, there are many neutron cross sections such as those on the fissile isotopes and the resonance parameters of other isotopes which cannot be calculated, but must be measured. We hope that this article points out that the neutron cross sections, even though they have been measured by a large number of the best scientists over a long period of years, are not adequate for designing novel reactors which will improve the economics of the nuclear energy program.

References

1) Progress in Fast Neutron Physics, edited by G.C. Phillips, J.B. Marion and J. R. Risser. U of Chicago Press, 1963.

2) Fast Reactor Cross Sections, edited by S. Yiftah, D. Okrent P.A. Moldauer, Pergamon Press, 1960.

3) L. Cranberg, R.A. Fernald, F.S. Hahn, and E.F.Shroder, Nuclear Instruments and Methods 12 (1961) 335-350;
A.B. Smith, Zertschrift fur Physik, 175, 5 (1963) 242.

4) J. Kistemaker, Nuclear Instruments and Methods 11 (1961) 179-184.
P.H. Rose, R.P. Bastide and A.B. Wittkower. R.S.I. 32, 581 (1961);
A.B. Wittkower, A. Galejs, P.H. Rose, and R.P. Bastide. R.S.I. 33, 515 (1962);
C.D. Moak, H.E. Banta, J.N. Thurston, J.W. Johnson and R.F. King, R.S.I. 30, 694 (1959);
A.B. Smith, Nuclear Phys. 47, 633 (1963).

5) C.A. Heusch and T. Springer, Nuclear Science and Engineering 10 (1961) 151;
H. Hurwitz, Proceedings of the 1st Geneva Conference on the Peaceful Uses of Atomic Energy. Vol. 4, pg. 328. United Nations, New York (1956);
W. B. Loewenstein and D. Okrent, Proceedings of the 2nd Conference on the Peaceful Uses of Atomic Energy. Vol. 12 p. 16. United Nations, Geneva (1958).

6) Proceedings of the International Atomic Energy Agency Conference on Fast Reactors (1961).

7) G. Goertzel et al. Proceedings of the First International Conference on the Peaceful Uses of Atomic Energy. United Nations, New York (1956);
A.M. Lore et al. Atomic Energy Research Establishment Report. A.E.R.E. T/M-137 (1956); Harwell, Berks., England
H.A. Bethe. Atomic Power Development Associates Report No. 119 (1957);
P. Grubler . I.R.E.A. Conference on Fast and Intermediate Reactors. Vienna, Austria (1961);
B. Nicholson . Atomic Power Development Associates Report No. 139 (1960); 1911 First Street, Detroit 26, Michigan.

8) Private communication from Dr. Norman Francis.

9) F. Perey and B. Buck, Nuclear Physics 32, (1962) 353.

10) R.B. Day, "Gamma Rays from Inelastic Neutron Scattering," Progress in Fast Neutron Physics (1963) 111-141.

11) B.C. Diven et al., Phys. Rev. 101 (1956) 1012.

12) G. Desaussure, et al., submitted for publication in Nuclear Science and Engineering.

13) W. W. Havens, Jr., H. Newson, "Neutron Resonance Phenomena," Progress in Fast Neutron Physics (1963) 232-251.

14) G. J. Safford and E. Melkonian, Phys. Rev. 113 (1959) 1285.

15) A. Saplakoglu, Proceedings of the 2nd United Nations Conference on the Peaceful Uses of Atomic Energy, Vol. 16 (United Nations, Geneva, 1958).

16) G. J. Safford, W. W. Havens, Jr., Nucleonics 17 (1959) 134.

17) J. E. Evans and R. G. Fluharty, Nuclear Science and Engineering, 8 (1960) 66.

Table 1 - $\sigma_{n,n}(E,\theta)$: Differential Cross Sections for Elastic Scattering

Element	Energy	Accuracy desired and Comments	Available Data and Comments
Li	2-14 MeV	10% desirable, 20% acceptable, in average of $<1-\cos\theta>$. For $E > 6$, what is really wanted is the sum of the elastic and inelastic angular distributions for which the final nucleus is in ground or first excited states.	Lane (ANL): Li^6, Li^7, up to 2.3 Bostrom et al (TNC) (WADC-TN-59-107): 1.4, 4.2 Batchelor, Towle (Physics Letters, '62): 1.5 - 7.5
Be	7-14 MeV	Same as for Li	
B	1.5-14 MeV	Same as for Li	Langsdorf et al (PR 107, 1957) 0.06 - 1.8 Phillips (LASL) (BAPS, 4, 358, 1959) 6, 6.3, 7
C	6-8, 10 MeV	Same as for Li	Wilenzick (Duke) (BAPS, 6, 252, 1961): 6 Bostrom et al (TNC)(WADC-TN-59-107): 7.6 Beyster et al (PR 104, 1319, 1956): 1-7.

Table 1 - $\sigma_{n,n}(E;\Theta)$: Differential Cross Sections for Elastic Scattering

Element	Priority Energy	Requestor	Accuracy Desired; Requestors' Comments	Available Data, at given energies (MeV) Comments by NCSAG
N	7-14		20%. 10% desirable, 20% acceptable, in average of $\langle 1 - \cos\Theta\rangle$. For $0^\circ < \Theta < 20^\circ$, data at 2.5° intervals, and with resolution of 2.5°, for $20^\circ < \Theta < 180^\circ$, data at 20° intervals and with angular resolution of 5°, are desired. Energy resolution better than 0.5 MeV wanted by ORNL; better than 1 MeV wanted by the others.	Phillips (LASL)(BAPS 4, 358, 1959); 7 Bostrom et al (TNC) (WADC-TR-57-446): 3.1, 3.5, 4.0, 4.3, 4.5, 4.8, 5.1, 7.1, 14.9, 15.8; Normalizations wrong but angular dependence OK; 14.1-MeV curve in BNL-400 normalized wrong, but angular dependence is probably OK. Davis (Rice): 5 - 8.5 Chase et al (Lockhead)(AFSWC-TR-61-15) 5.0, 5.7, 6.0, 6.5, 8.0, 11.6. Strizhak et al (ZETF 41, 313, 1961): 14
N	2-7 MeV			
N	1-2 MeV		Same as above	See above also Fowler et al (PR 98, 728, 1955): 1.0 - 2.4
N	2.4-14 MeV		Same as for Li	
O	7-14 MeV		20%. 10% desirable, 20% acceptable in average of $\langle 1-\cos\Theta\rangle$ For $0^\circ < \Theta < 20^\circ$, data at 2.5° intervals and with resolution of 2.5° for $20^\circ < \Theta < 180^\circ$, data at 20° intervals and with angular resolution of 5°, are desired. Energy resolution better than 0.5 MeV wanted. Good resolution data requested at 100 kev intervals in 3-4 MeV range to	Phillips (LASL)WASH-1028 for * values) 3.00*, 3.35, 3.50 3.55, 3.65, 3.75, 6.0*, 7.0 Smith (BAPS 5, 19, 1960): 5.0, 6.5 Sayres (Columbia): 3-4. Hunzinger, Huber (HPA 33, 570 '60): 2-4 Chase: Same as for N Bostrom: Same as for N
O	3-7 MeV			

Table 1 - $\sigma_{n,n}(E; \Theta)$: Differential Cross Sections for Elastic Scattering

Element	Priority Energy	Accuracy desired; Requestors' Comments	Available Data, at given energies (MeV); Comments by NCSAG
O	1-3 MeV	Same as given for O on previous page, where applicable.	Same as given for O on previous page.
O	3-14 MeV	High resolution data needed at 25 KeV intervals from 3-4 MeV to unravel properties of the resonance. Low resolution data preferred above 4 MeV.	Same as given for O on previous page.
Si	2-14 MeV	10% (or at least 20%) in σ and in average of $\langle 1 - \cos \Theta \rangle$. Energy resolution better than 1 MeV	
Ca	6-14 MeV	Same as for Si	Vincent et al (TNC) (WADD-TR-60-217): 4.1 Cranberg (LASL): 6.0
V	1.5 MeV and up	10% (or at least 20%) in average of $\langle 1-\cos \Theta \rangle$.	
Fe	Up to 1 MeV	Same as for V	Langsdorf et al (PR 107, 1077): .06 - 1.8 Gilboy (AWRE): 1 Smith (ANL): 0.8, 1.0, 1.2, 1.4, 1.6
Fe	5-10 MeV		Hill (PR 109, 2105, 1958): 5 Wilenzick et al (Duke): 6 Beyster et al (PR 109. 2105, 1958): 5

Table 1 - $\sigma_{n,n}(E;\Theta)$: Differential Cross Sections for Elastic Scattering

Element	Priority Energy	Accuracy desired: Requestor's Comments	Available Data, at given energies (MeV) Comments by NCSAG
Ni	5-10 MeV		Hill (PR 109, 2105, 1958):5
Th	1.5-5 MeV	10% (or at least 15%) in average of $\langle 1 - \cos\Theta \rangle$.	Smith (ANL): 1.5 Hudson et al (BAPS 6. 251, 1961): 15 MeV
U^{235}	1.5-7 MeV	10% in average of $\langle 1 \cos\Theta \rangle$.	Smith (ANL): 1.5 Cranberg (LA-2177, 1959): 2
U^{238}	2-7 MeV	10% in average of $\langle 1 - \cos\Theta \rangle$. What is really desired is σ_{tr}	Cranberg et al (PR 109, 2063, 1958):2 Walt, Beyster (LA-2061): 2.5
Pu^{239}	0.05-10 MeV	Same as for U^{238}	Cranberg (LA-2177): 0.55, 1,2.

Table 2 - Nonelastic Processes

El.	Cross Section	Priority Energy	Accuracy Desired Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
D	$\sigma_{n,2n}(E;E'\Theta)$	Up to 14 MeV	10%(or at worst, 20%). Even only one result near 10 MeV would be helpful.	
T	$\sigma_{n,2n}(E;E'\Theta)$	Up to 14 MeV	Same as for D	
Be	$\sigma_{n,2n}(E)$	Up to 5 MeV	15%. In 2-3 MeV range, 50 mb.	Figure 15 of WASH-1028 gives 1960 status.
Be	$\sigma_{nM}(E;E')$ $\sigma_{nM}(E;E'\Theta)$	5-14 MeV	10% (or at worst, 20%) in σ and in average of $\langle 1-\cos\Theta\rangle$. Angular distribution important only if nonelastic processes are significantly anisotropic.	
Li^6	$\sigma_{n,n'}(E;E'\Theta)$	2.5-14 MeV	10% (or at worst, 20%).	Wong et al(Nuc. Phys. 33, 680, '62): Some data at 14.

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Li^7	$\sigma_{n,n'}(E;E',\Theta)$	2.5-14 MeV	10% (or at worst, 20%).	Wong et al (Nuc. Phys. 33, 680, '62): 14
B^{10}	$\sigma_{nD}(E)$	1-14 MeV	10% (good energy resolution not required).	
B^{10}	$\sigma_{nM}(E;E')$	1-14 MeV	Ditto	
B^{10}	$\sigma_{nM}(E;E',\Theta)$	1-14 MeV	Ditto	
B^{10}	$\sigma_{nD}(E)$	1-1000 KeV	Ditto	Davis et al (N.P. 27, 448, 1961): charged particle emission, 0-8 MeV.
N	$\sigma_{nM}(E;E')$ $\sigma_{nM}(E;E'\Theta)$	7-14 MeV	20%. 10% desired (but 20% acceptable) in average of $\langle 1-\cos\Theta\rangle$ if non-elastic processes are significantly anisotropic. Resolutions: ΔE, $\Delta E'$ both $\leqslant$ 1 MeV.	

Table 2 - Nonelastic Processes

El.	Cross Section	Priority Energy	Accuracy Desired Other Comments	Available Data, at given energies (MeV) Comments by NCSAG
N	$\sigma_{nG}(E;E_\gamma)$	8-14 MeV; $E\gamma > 0.5$	10% (or at worst, 20%. Angular distribution of gammas requested if badly anisotropic. Resolutions: $\Delta E \leqslant 1$ MeV ($\leqslant 0.5$ MeV for ORNL); $\Delta E_\gamma \leqslant 0.5$ MeV (or at worst $\leqslant 1$ MeV).	
N	$\sigma_{nG}(E;\ E_\gamma)$	4-8 MeV	20% Resolutions: $\Delta E \leqslant 0.5$ MeV; $\Delta E_\gamma \leqslant 0.5$ MeV (or at worst $\leqslant 1$ MeV).	
N	$\sigma_{nG}(E;E_\gamma,\psi)$	4-14 MeV $E\gamma > 4$	20% Resolution: $\Delta E_\gamma \leqslant 20\%$.	
N	$\sigma_{n,\ n'}(E;E',\Theta)$	0-14 MeV	20%.	
O	$\sigma_{nM}(E;E')$ $\sigma_{nM}(E;E',\Theta)$	10-14 MeV	20%. 10% desired (but 20% acceptable)in average of $<1 - \cos\Theta>$ if nonelastic processes are significantly anisotropic. Resolution: ΔE, $\Delta E'$ both $\leqslant 1$ MeV.	

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
O	$\sigma_{nM}(E;E')$ $\sigma_{nM}(E;E',\Theta)$	7-10 MeV	20%. 10% desired (but 20% acceptable) in average of $<1 - \cos\Theta>$ if non-elastic processes are significantly anisotropic. Resolution: ΔE, $\Delta E'$ both $\leqslant 1$ MeV.	
O	$\sigma_{nG}(E;E_\gamma)$ $\sigma_{nG}(E;E_\gamma,\psi)$	10-14 MeV $E\gamma$ 0.5	10% (or at worst, 20%). Angular distribution of gammas requested if badly anisotropic. Resolutions: $\Delta E \leqslant 1$ MeV ($\leqslant$ 0.5 MeV for ORNL); $\Delta E_\gamma \leqslant 0.5$ MeV (or at worst $\leqslant 1$ MeV.)	
O	$\sigma_{nG}(E;E_\gamma)$	4-10 MeV	20% Resolutions: $\Delta E \leqslant$ 0.5 MeV; $\Delta E_\gamma \leqslant 0.5$ MeV (or at worst $\leqslant 1$ MeV).	
O	$\sigma_{nD}(E)$	9-14 MeV	20%.	
Na	$\sigma_{n,n'}(E;E')$	2-14 MeV		Towle, Gilboy (N.P. 32, 610, 1962); 1.0, 1.5, 2.5, 4.0

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired; Other Comments	Available data, at given energies (MeV); Comments by NCSAG
Al	$\sigma_{n,n'}(E;E')$	0-14 MeV	20% Energy resolution may be low except near threshold.	Thomason (LASI '60): Nuc. Temp. at 7. Nellis et al (BAPS 7, 120, J6, 1962): Inelastic gammas at 4.0, 14.8.
Al	$\sigma_{nM}(E;E')$	Up to 14 MeV	10% (or at worst, 25%). If angular distribution is strongly anisotropic, 10% (or at worst 20%) in average of $<1 \quad \cos\Theta>$ Resolution: ΔE, $\Delta E'$ both $\lesssim 1$ MeV.	Weddell (Phys. Rev. 104, 1069, 1956); 4.4 MeV at 82°.
Al	$\sigma_{nG}(E;E_\gamma)$ $\sigma_{nG}(E;E_\gamma, \psi)$	2-14 MeV	10% (or at worst 25%). Angular distribution of gammas requested only if strongly isotropic. Resolution: $\Delta E \lesssim 1$ MeV; ΔE_γ <0.5 MeV.	
Si	$\sigma_{nM}(E;E')$ $\sigma_{nM}(E;E',\Theta)$	3-14 MeV	10% (or at worst 20%). Angular distribution requested if nonelastically scattered neutrons are strongly anisotropic. Resolution: $\Delta E < 1$ MeV.	Stelson (ORNL) has some results at 14 MeV.

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Si	$\sigma_{nG}(E;E_\gamma)$ $\sigma_{nG}(E;E_\gamma,\psi')$	3-14 MeV; $E_\gamma \geq 0.5$	10% (or at worst, 20%). Angular distribution requested if gammas are strongly anisotropic. Resolutions: $\Delta E \gtrsim 1$ MeV; $\Delta E_\gamma \geq 0.5$ MeV .	Hall, Bonner (WASH-1028, pp. 60,62); E up to 4.5, $E_\gamma = 1.78$, $= 90^\circ$ Lind, Day (ANN. Phys. 12, 485, 1961): $E = 1.5-3.0$, $E_\gamma = 1.78 - 2.41$, $= 94^\circ$ only.
Si	$\sigma_{n,n'}(E;E')$	1.8-14 MeV	50%, but 10% in $\sigma_{n,n'}(E)$.	
Si^{28}	$\sigma_{n,p}(E)$	Up to 14 MeV	10%; good energy resolutions not required	
K	$\sigma_{n,p}(E)$ and $\sigma_{n,\alpha}(E)$	Up to 2 MeV	25%, or 10 mb (whichever is larger).	Haenni (Rice) (WASH-1026, p. 55, 1959); (WASH-1028, p. 60, 1960): Up to 8.5.
Ca	$\sigma_{nM}(E;E')$ $\sigma_{nM}(E;E',\Theta)$	Up to 14 MeV	10% (or at worst, 20%). If nonelastic processes are strongly anisotropic, angular distribution is requested good to 10% (or at worst 20%) in average of $\langle 1 \cos \Theta \rangle$. Resolution: ΔE , $\Delta E'$ both < 1 MeV.	

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV) Comments by NCSAG
Ca	$\sigma_{nG}(E;E_\gamma)$ $\sigma_{nG}(E;E_\gamma, \eta')$	4-14 MeV $E_\gamma \geq 0.5$	10% (or at worst 20%). If gamma rays are significantly anisotropic, their angular distribution is requested good to 10% (or at worst 20%) in average of $\langle 1 \cos \Theta \rangle$. Resolution $\Delta E \leqslant 1$ MeV, $\Delta E_\gamma < 0.5$ MeV.	
Ca	$\sigma_{n,n'}(E;E')$	3.4-14	50%, but 10% in $\sigma_{n,n'}(E)$.	
V	$\sigma_{n,n'}(E;E')$	0-14	15%.	Thomson (LASL '60): Nuc. Temp. at 7 MeV.
Cr	$\sigma_{nG}(E;E_\gamma)$	2.5 - 10 MeV E_γ 1	10% (or at worst 25%). Resolution: $\Delta E = 0.5$ MeV, $\Delta E_\gamma = 1$ MeV. Data on separated isotopes would be helpful.	
Mn	$\sigma_{n,2n}(E;E')$ $\sigma_{n,2n}(E;E',\Theta)$	Up to 14 MeV	20%. Angular distribution requested if strongly anisotropic. Resolution: $\leqslant 1$ MeV.	Remy, Winter (C.R. 246, 1410, 1958): E' spectrum at 14. Weigold (Australian J. Phys. 13, 186, '60): $\sigma_{n,2n}(E) = 825$ mb at E = 14.5.

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV) Comments by NCSAG
Ni	$\sigma_{nG}(E;E_\gamma)$	2.5-14 MeV E_γ 0.5	10% (or at worst 25%).	
Sr^{87}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 2.8-h isomer. Low resolution OK.	
Zr	$\sigma_{n,n'}(E;E')$	1-4 MeV	20%. Good resolution needed near thresholds for separate isotopes.	Smith (ANL '62): 0.5, 0.7, 1.2, 1.6.
Zr	$\sigma_{n,n'}(E;E')$	3-4 MeV	10% in $\sigma_{n,n'}(E)$	Lind, Day (Ann. Phys. 12, 485, 1961): Production of γ's at 94° for 1-4 MeV.
Zr	$\sigma_{n,n'}(E;E')$	4-14 MeV	20%	Nellis, Morgan, Ashe (BAPS 7, 120 J6, '62): Production of γ's at 90° for 4 and 14 MeV.
Nb	$\sigma_{n,n'}(E;E')$	Up to 3 MeV	15%. Data for a single E should suffice.	Thomson (LASL '60): Nuc. Temp. at 5. Smith (ANL) in progress up to 1.2. Seth et al (Duke '61) has E' spectrum for 6 MeV.

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Mo	$\sigma_{n,n'}(E;E')$	Up to 3 MeV	20%.	
Cd^{111}	$\sigma_{n,n'}(E)$	Up to 14 MeV.	15% in σ_{act} to 48.6m isomer. Low resolution OK.	
Sn^{117}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 14-d isomer. Low resolution OK.	
Sn^{119}	$\sigma_{n,n'}(E)$	Up to 14 MeV.	15% in σ_{act} to 275-d isomer. Low resolution OK.	
Te^{123}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 104-d isomer. Low resolution OK.	
Te^{125}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 58-d isomer. Low resolution OK.	
Ba^{135}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 28.7-h isomer. Low resolution OK.	

Table 2 — Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Ba^{137}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 2.6-m isomer. Low resolution OK.	Swann, Metzger (PR 100, 1329, 1955): 0.5 - 3.0.
Er^{167}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 2.5-s isomer. Low resolution OK.	
Hf^{179}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 19-s isomer. Low resolution OK.	
W	$\sigma_{n,n'}(E;E')$	1.5-4 MeV		Smith (ANL) (WASH-1031-'60): 0.3 - 1.5. Thomson (LASL '60) has nuc. temp. at 7.
W	$\sigma_{n,n'}(E;E_\gamma)$	0.5-14 MeV $E_\gamma > 0.5$		
Pt^{195}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 4.1-d isomer. Low resolution OK.	
Hg^{199}	$\sigma_{n,n'}(E)$	Up to 14 MeV	15% in σ_{act} to 42-m isomer. Low resolution OK.	

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Pb	$\sigma_{n,n'}(E;E_\gamma)$	2.5-14 MeV	Isotopic identification is desirable.	Day (LASL) has data from 0.5 to 3.2 MeV.
Pb	$\sigma_{n,n'}(E;E')$	2.5-14 MeV	Isotopic identification is desirable.	Thomson (LASL '60) has temps. at 4 and 7 for Pb^{206}
				Morgan (TNC) (WADC-59-31, '59): 3.7, 4.2, 4.7, 15.
				Seth et al (Duke '61) has E' spectrum at 6 Mev and 90°.
				Sal'nikov (JNE 8, 119, 1958): 2.35.
				Popov (JNE 9, 9, 1959): 2.9.
Bi	$\sigma_{n,n'}(E;E_\gamma)$	2.8-14 MeV		Bonner (Rice): 4 - 8.
Th^{232}	$\sigma_{n,n'}(E;E')$	Up to 4 MeV	20%. 5% in $\sigma_{n,n'}(E)$	Smith (ANL) (WASH-1033, '61): 0.3 - 1.6.
				Lind and Day (LASL): high energy gamma excitations up to 1.5 MeV neutron energy.
U^{233}	$\sigma_{n,n'}(E;E')$	Up to 7 MeV	10%-15%. However, $\sigma_{n,n'}(E)$ and the fractions of the E' spectrum above and below Th^{232} and U^{238} fission thresholds should be good to 5%-10%.	

Table 2 - Nonelastic Scattering

El.	Cross Section	Priority Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
U^{235}	$\sigma_{n,n'}(E;E')$	6-14 MeV	5%-10%. Even one measurements near 10 would help.	
U^{235}	$\sigma_{n,n'}(E;E')$	0.1-0.5, 2-10 MeV	10%-15% in $\sigma_{n,n'}(E)$.	Cranberg (LA-2177 '59): 0.55, 1, 2. Smith (ANL) is doing low energy region.
U^{235}	$\sigma_{n,n'}(E;E')$	2.5-12 MeV	10%. Resolution: 20% in ΔE, $\Delta E'$ is OK.	
U^{235}	$\sigma_{n,n'}(E;E')$	0.5-7 MeV	Same as for U^{233}; (See previous page.)	
U^{238}	$\sigma_{n,n'}(E;E')$	6-14 MeV	5%-10%. Even one point near 10 would help.	
U^{238}	$\sigma_{n,n'}(E;E')$	45-750 KeV	10%. Excitation curves for levels below 750 KeV.	
U^{238}	$\sigma_{nM}(E;E')$	0.75-10 MeV	5%-20%. $N_M(E)$ also desired.	Cranberg et al (PR 109, 2063 '58): 0.5, 1, 2. Smith (ANL) (WASH-1029): 0.5-1.5. Seth et al (Duke '61) has E_0' spectrum at 6 MeV and 90°.
Pu^{240}	$\sigma_{n,n'}(E;E')$	6-14 MeV	5%-10%.	
Pu^{240}	$\sigma_{nM}(E;E')$	Up to 7 MeV	20%. Nuclear temperature may suffice.	

Table 3 - and $\sigma_{n,\gamma}(E)$: Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired: Other Comments	Available Data at given energies (MeV); Comments by NCSAG
K	$\sigma_{n,\gamma}(E)$	30 KeV 2.0 MeV	25%, or at least 10 mb	Macklin (ORNL): 30 and 65 KeV Kononov et al (JNE 11, 46, '59): at 25 KeV, K^{41} has $\sigma_{n,\gamma}<$ 26 mb.
K	$\sigma_{nT}(E)$	1.4 - 14 MeV	10% Resolution: ΔE < 0.5 MeV.	
Ca	$\sigma_{nT}(E)$	6-14 MeV	10% Resolution: ΔE < 0.5 MeV (or at worst <1 MeV).	
Ca	$\sigma_{nT}(E)$	0.6-3 MeV	3%	Wilenzick (Duke,'60) (WASH-1029): up to 1 Shrader (Case) will do.
V	$\bar{\sigma}_{n,\gamma}(E)$	1-150 KeV	10%	Macklin et al(PR 107, 504, '57): 25 KeV. Kononov et al (JNE 11, 46, '59): 25 KeV. Gibbons et al (PR 122, 192, '61): 30 KeV. Stavisskii et al (SJAE 9, 942, '61): V^{51}
Cr	$\sigma_{n,\gamma}(E)$	1-150 KeV	25% or at worst 10 mb.	Gibbons et al (See V above): 30, 65 KeV. Diven et al (PR 120, 556, '60): 175-1000 KeV. Belanova (SJAE, 8, 462, '61): σ_{nD} at 24, 220, 830 KeV.

Table 3 - $\sigma_{n\gamma}(E)$: Fast Total and Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Mn	$\sigma_{n,\gamma}(E)$	1-40 KeV.	20%. Capture widths for several resonances may suffice.	Kononov et al (JNE 11, 46, '59): 25 KeV. Bostrom et al (WADC-59-107, '59): 40-3000 KeV. Stavisskii et al (SJAE 10, 498, '62): 30-2000 KeV.
Fe	$\sigma_{n,\gamma}(E)$	0-175 KeV.	10%, or at worst a few mb	Gibbons et al (PR 122, 192, '61): 30, 65 KeV. Diven et al (PR 120, 556, '60): 175-1000 KeV. Stavisskii et al (SJAE 10, 255, 498 1962): 12-1000 KeV. Belanova (SJAE 8, 462, '61): 220 KeV.
Fe	$\sigma_{n,\gamma}(E)$	1-2 MeV.	10%, or at worst, a few mb. Capture resonances in 1-5 KeV ranges are also of interest.	
Ni	$\sigma_{n,\gamma}(E)$	0.5-175 KeV.	25%, or at worst 10 mb.	Gibbons et al (PR 122, 192, '61): 30, 65 KeV. Stavisskii et al (See Fe above): 34-1000 KeV. Kononov et al (JNE 11, 46, '59); $\sigma < .037$ b at 25 KeV.

Table 3 - $\sigma_{n\gamma}(E)$: Fast Total and Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Ni^{64}	$\sigma_{n,\gamma}(E)$	0-100 KeV.	10% (but 1% in resonance energies). Resonance parameters and σ_{nT} data would be a help.	Booth (P.R. 112, 226, '59): σ = 8.7 mb at 25 KeV. Grench et al (B.A.P.S. 6, 430, '61): $\sigma_{n\gamma}$(100 KeV) = 3 mb.
Y	$\sigma_{n,\gamma}(E)$	0-1 MeV.	15%.	Gibbons et al (P.R. 122, 182, '61): 30, 65 KeV. Bostrom et al (WADC-59-107, '59): 100-680 KeV. Newson (Duke): up to 100 KeV.
Nb	$\sigma_{n,\gamma}(E)$	1 KeV 1 MeV	Repeat to resolve possible discrepancy at 175 KeV.	Kononov et al (J.N.E. 11, 46, '59): 25 KeV. Gibb ons (See Y above): 7 - 175 KeV. Diven et al (P.R. 120, 556, '60): 175 - 1000 KeV. Stavisskii et al (S.J.A.E. 9, 942, '61): 25-1500 KeV.
Nb	$\sigma_{n,\gamma}(E)$	1-2 MeV.	25%, or at worst 10 mb.	Stavisskii et al (S.J.A.E. 10, 255, '62): 20-1000 KeV.

Table 3 - $\sigma_{n\gamma}(E)$: Fast Total and Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Ru	$\sigma_{n,\gamma}(E)$	1-150 KeV.	10%.	Macklin et al (P.R. 107, 504, '57): has σ_{act} for 3 isotopes at 25 KeV.
				Block (Saclay Symposium, 1961): up to 9 KeV.
Rh	$\sigma_{n,\gamma}(E)$	1-150 KeV.	10%.	Gibbons et al (P.R. 122, 182, '61): 65.
				Block (See Ru above): up to 9 KeV.
Hg	$\sigma_{n,\gamma}(E)$	1-1000 KeV.	20%.	Gibbons (See Rh above): 30, 65 KeV.
W	$\sigma_{n,\gamma}(E)$	1-2 MeV.		Diven et al (P.R 120, 556, '60): 175 - 1000 KeV.
				Gibbons (See Rh above): 10-170 KeV.
Pb	$\sigma_{n,\gamma}(E)$	1-50 KeV.	Any p-wave resonances?	Schmitt et al (N.P. 20, 202, '60): 24 KeV.
				Tattersall et al (J.N.E. 12, 32,'60)
Bi	$\sigma_{n,\gamma}(E)$	1-30 KeV.	25%, or at worst 5 mb. At low energies resonance parameters alone may suffice.	Gibbons et al (See Rh above): 30, 65 KeV.
				Lynn et al (N.P. 7, 613, '58): 0.3-4 KeV.
				Firk et al (B.A.P.S. 4, 34, '59):

Table 4 - Resonance Parameters and Radiative Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired Other Comments	Available Data, at given energies (MeV): Comments by NCSAG
Al	$\sigma_{nT}(E)$ $\sigma_{n,\gamma}(E)$	5.9 KeV 35 KeV	Parameters wanted (particularly Γ_γ for these two resonances.	
Ca	$\sigma_{nT}(E)$	Up to 10 KeV	5% Resolution sufficient to resolve any resonances in range.	
Ca	$\sigma_{nT}(E)$	Up to 1 KeV	Parameters wanted for any resonance in range	
Mn	$\sigma_{n\gamma}(E)$	Up to 100 eV	25% Resolution: $\Delta E < 20\%$.	
Mn	$\sigma_{n,\gamma}(E)$	Up to 1 KeV	2% near thermal; 5% in resonance region. For activation standard in reactor flux measurements.	Resonance integral is fairly well-known. A 5% measurement of Γ_γ for 337 eV resonance should be helpful.
Mn	$\sigma_{n,\gamma}(E)$	0-25 KeV	20% or at worst, 5 mb. Resolution sufficient to resolve any resonances in range.	Macklin et al (PR 107), 504, 55 mb at 25 KeV. Booth et al (PR 112), 226 '58, 52 mb at 25 KeV. Kononov et al (JNE 11, 46 , '59): 65 mb at 25 KeV

Table 4 - Resonance Parameters and Radiative Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV) Comments by NCSAG
Co	$\sigma_{nT}(E)$, $\sigma_{n,\gamma}(E)$	132 eV	1% in parameters of this resonance. For activation standard in reactor flux measurements.	Firk (Harwell '61): $\Gamma_\gamma = 0.70 \pm .20$ eV. Block (WASH-1029, '60): $\Gamma_\gamma = 0.67 \pm .15$ eV. Jain (BNL '62): $\Gamma_\gamma = 0.416 \pm .028$ eV.
Cu^{63}	$\sigma_{n,\gamma}(E)$	0-1 KeV.	2% near thermal ; 5% in resonance region.	
Cu^{65}	$\sigma_{n,\gamma}(E)$	0-1 KeV.	2% near thermal; 5% in resonance region.	
Kr^{83}	$\sigma_{nT}(E)$, $\sigma_{n,\gamma}(E)$	Up to 1 KeV.	50% in resonance absorption integral.	Mann et al (P.R. 116, 1516, '59): Some Γ's for 28 eV and 233 eV resonances. Walker (CRRP-913, '60): estimates RI - 240.
Y	$\sigma_{n,\gamma}(E)$	Up to 500 eV.	15%.	
Zr^{90}	$\sigma_{nT}(E)$, $\sigma_{n,\gamma}(E)$	Up to 10 KeV.	10% in parameters.	Block (ORNL'62): $E_r = 3.88, 13.5, 17.8$ KeV.

Table 4 - Resonance Parameters and Radiative Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Zr^{91}	$\sigma_{nT}(E)$, $\sigma_{n,\gamma}(E)$	Up to 10 kev.	10% in parameters.	Block (ORNL '62): E_r = 0.18, 0.24, 0.29, 0.43, 0.68, 0.90, 1.54, 1.82 1.99, 2.49, 2.74, ... Feiner (KAPL-2000-8, '59): RI = 5.4 $\pm$ 1.6
Zr^{92}	$\sigma_{nT}(E)$, $\sigma_{n,\gamma}(E)$	Up to 10 kev.	10% in parameters.	Block: E_r = 2.70, 4.14, 4.67, 6.89,...
Zr^{94}	$\sigma_{nT}(E)$, $\sigma_{n,\gamma}(E)$	Up to 10 kev.	10% in parameters.	Block: E_r = 2.25, 5.84, 7.10, 12.6,...
Zr^{96}	$\sigma_{nT}(E)$, $\sigma_{n,\gamma}(E)$	Up to 10 kev.	10% in parameters.	Block: E_r = 0.30, 2.69, 3.[illegible] 4.11, 5.43, 5.94,...
Rh	$\sigma_{nT}(E)$, $\sigma_{n,\gamma}(E)$	Up to 10 kev.	10% in resonance absorption integral calculated from parameters.	Macklin et al (Geneva Conf. 5, 96, '55): RI = 575 (exp't), 656 (exp't), 1146 (calc.). Walker (CRRP-913,'60):RI=1095 (calc.). Chrien et al (BNL '59): $2g\Gamma_n$ for 12 resonances, 44-326 ev. Ribon et al (J. Phys. Rad. 22, 707, '61): E_r =47, 68, 96. Block (Saclay Symposium, 1961): 0.2 - 9 kev.

Table 4 - Resonance Parameters and Radiative Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Cs	$\sigma_{nT}(E)$ $\sigma_{n,\gamma}(E)$	Up to 1 kev.	10% in RI calculated from parameters.	17 resonances known, 6 - 530 ev. Tattersall (AERE-R/2887, '59): RI = 504. Eiland (KAPL-2000-11, '60): RI = 400 $\pm$ 25. Persiani (ANL Newsletter No. 1): RI = 394 (calc.).
Nd^{143}	$\sigma_{nT}(E)$ $\sigma_{n,\gamma}(E)$	0-1 kev.	Parameters to give 10% in RI.	Stolovy et al (P.R. 108, 352, '57): 7 resonances between -8 and +190ev.
Pm^{147}	$\sigma_{nT}(E)$ $\sigma_{n,\gamma}(E)$	0-1 kev.	Parameters to give 10% in RI.	Schuman et al (N.S.E. 12, 519, '62): RI to each isomer of Pm. Harvey (Geneva Conf. 16, 150, '58): 12 resonances between 1 and 50 ev.
Sm^{151}	$\sigma_{nT}(E)$ $\sigma_{n,\gamma}(E)$	0-1 kev.	Parameters to give 10% in RI.	Pattenden (ORNL '61): RI= 3000 b 7 resonances between -0.015 and 10.45ev. Harvey (Geneva Conf. 16, 150, '58): 5 resonances between 1.1 and 6.3 ev.
Eu^{151}	$\sigma_{n,\gamma}(E)$	0-1 kev.	2% near thermal; 5% in resonance region.	Tattersall (J.N.E. 12, 32,'60): RI < 6900 b (exp't). Persiani (Argonne Newsletter No.1,'61): RI = 7320 (calc.) Moore et al (KAPL-2000-8, '59): Ratio of Eu^{152} isomers produced: (13-y/9-h) = 2.1.

Table 4 - Resonance Parameters and Radiative Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Eu^{153}	$\sigma_{n,\gamma}(E)$	0-1 kev.	2% near thermal; 5% in resonance region.	Tattersall (J.N.E. 12, 32, '60): RI = 1500 (exp't). Persiani (Argonne Newsletter No. 1, '61): RI = 1760 (calc.).
Eu^{154}	$\sigma_{nT}(E)$ $\sigma_{n,\gamma}(E)$	0-1 kev.	10% in resonance parameters.	
Eu^{155}	$\sigma_{nT}(E)$ $\sigma_{n,\gamma}(E)$	0-1 kev.	10% in resonance parameters.	
Er	$\sigma_{n,\gamma}(E)$	0-1 kev.	4% Resolution: $\Delta E < 10\%$	Haddad et al (GA) (B.A.P.S. 7, 455, GA15, Sept. '62): 34 resonances, 3 - 142 ev.
Hf	$\sigma_{n,\gamma}(E)$	0-1 kev.	Parameters to give 10% in RI.	Tattersall (J.N.E. 12, 32, '60): RI = 2900 (exp't), 2050 (calc.). Spivak (Geneva Conf. 5, 91, '55): RI = 2800 Feiner et al (B.A.P.S. 7, 22, '62): RI = 2000. Harvey (ORNL) will do. Block (Saclay Symposium, '61): 0.2 - 9 kev.

Table 4 - Resonance Parameters and Radiative Capture Cross Sections

El.	Cross Section	Energy	Accuracy Desired: Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Hf^{176}	$\sigma_{n,\gamma}(E)$	0-1 kev.	Parameters to give 50% in RI.	Harvey (ORNL) and Russell (RPI) will do.
Hf^{177}	$\sigma_{n,\gamma}(E)$	0-1 kev.	Parameters to give 10% in RI.	Vidal (Fontenay, '61): RI = 4800.
Hf^{178}	$\sigma_{n,\gamma}(E)$	0-1 kve.	Parameters to give RI to 10%.	Vidal (Fontenay): RI = 1900.
Hf^{179}	$\sigma_{n,\gamma}(E)$	0-1 kev.	Parameters to give RI to 10%.	Vidal (Fontenay): RI = 300.
Hf^{180}	$\sigma_{n,\gamma}(E)$	0-1 kev.	Parameters to give RI to 15%.	Macklin (Geneva Conf. 5, 96, '55): RI = 21.8.

Table 5 - Fissile and Neighboring Nuclei

Isotope	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Th^{232}	$\sigma_{n,\gamma}(E)$	Up to 500 ev.	5% or better.	Moxon (Harwell, '62): 5 - 20,000 ev. Rainwater (Columbia): σ_T up to 4000 ev. Tattersall (J.N.E. 12, 32, '60): RI = 110. Johnston (J.N.E. 11, 95, '60): RI=85.
Th^{232}	$\sigma_{n,\gamma}(E)$	0.5-1000 kev.	5%	Block (ORNL-2910, 1960) Macklin (P.R. 107, 504, '57): 25 kev. Hanna et al (J.N.E. 8, 197, '59): 100 - 297. Stavisskii et al (S.J.A.E. 10, 255, '62): 30 - 2000. Berry et al (P.P.S. 74, 685, '59): 300 - 1200. Lindner (UCRL-5454, '59): 240 - 3000.
Pa^{233}	$\sigma_{n,\gamma}(E)$	Up to 500 ev.	5%	Preparations are under way for measurement with MTR fast chopper. See: F. B. Simpson (Saclay Symposium on Time-of-Flight Methods, 1961).
Pa^{233}	$\sigma_{n,\gamma}(E)$	0.5 - 1000 kev.	To within a factor of 2 (Priority II). 20% (Priority III).	Intrinsic sample radioactivity precludes measurements by means available now.

Table 5 - Fissile and Neighboring Nuclei

Isotope	Cross Section	Energy	Accuracy Desired Other Comments	Available Data at given energies (MeV); comments by NCSAG
U^{233}	$\sigma_{n,f}$	0.025 eV	0.5%	
U^{233}	$\sigma_{n,f}(E)$	.025-100 eV	2%	Moore et al (PR 118, 714, '60).
U^{233}	$\sigma_{n,f}(E)$	700-30 KeV	3%	
U^{233}	$\alpha(E), \eta(E)$ or $\sigma_{n,\gamma}(E)$	0.01-10 eV	1% in relative values of η	Harvey (RPI Symposium, '61): σ_T to 30 eV. η good to 3 eV Moore, Reich (PR 118, 718, 1960): Multilevel fit to 11eV
U^{233}	$\alpha(E), \eta(E)$	10 eV	3% or at worst 5%.	Moore et al (PR 118, 714, '60) σ_T to 200 eV.
	$\sigma_{n,\gamma}(E)$	1 KeV		
U^{233}	Ditto	1-30 KeV.	2% in η.	de Saussure, Weston (ORNL): 10-500 KeV.
U^{233}	Ditto	30 KeV 2.5 MeV	0.5% in η	Hopkins, Diven (NSE 12, 169, 1962): 30 KeV - 1 MeV.
U^{233}	Ditto	2.5-7 MeV.	2% in η	

Table 5 - Fissile and Neighboring Nuclei

Isotope	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
U^{233}	$\bar{\nu}(E)$	10-1000 ev.	3%, or at worst 5%.	
U^{233}	$\bar{\nu}(E)$	1-30 kev.	2%	Hopkins and Diven (LASL) have measured at a few energies, 325 kev - 4 mev.
U^{233}	$\bar{\nu}(E)$	30 kev. - 2.5 mev.	0.5%	Preliminary values appear in Table 6 on page 22 of WASH-1034. Later values are in WASH-1041.
U^{233}	$\bar{\nu}(E)$	2.5-7 mev.	2%	
U^{234}	$\sigma_{nT}(E)$ $\sigma_{n,\gamma}(E)$	Up to 1 kev.	Resonance parameters: 5% in Γ_n; 10% in Γ_γ.	Harvey et al (P.R. 109, 471, '58) McCallum (J.N.E. 6, 181, '57) 21 resonances between (-2.0) and 369 ev. known, but not to detail desired.
U^{234}	$\sigma_{n,\gamma}(E)$	1 kev. to several mev.	15%	
U^{234}	$\bar{\nu}(E)$	One point above threshold.	10%	

Table 5 - Fissile and Neighboring Nuclei

Isotope	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
U^{235}	$\sigma_{n,f}(E)$	0.025-1000 ev.	10%, or at worst, 15%.	Bowman et al (LRL) (UCRL-6926, '62): 0.03 - 60 ev. throws doubt over previous work.
U^{235}	$\alpha(E)$ or $\sigma_{n,\gamma}(E)$	0.025 ev. - 30 kev.	3% in $(1 + \alpha)$. Posible discrepancy between $\alpha(E)$ and results of integral measurements needs resolving.	Brooks (RPI Symposium, '61): 1 - 33 ev. Brooks (Saclay Symposium, '61): 1 - 50 ev. Smith (MTR): up to 10 ev.
U^{235}	$\alpha(E)$ or $\sigma_{n,\gamma}(E)$	30 - 150 kev.	3%	de Saussure and Weston (ORNL): 5 - 1000 kev.
U^{235}	$\alpha(E)$ or $\sigma_{n,\gamma}(E)$	150 kev. - 7 mev.	5%, or at worst 10%; resolution may be low.	Hopkins, Diven (N.S.E. 12, 169, '62): α, 30 - 1000 kev.
U^{235}	$\eta(E)$	0.025 ev.-50 kev.	2%	
U^{236}	$\begin{cases}\sigma_{nT}(E)\\ \sigma_{n,\gamma}(E)\end{cases}$	Up to 1 kev.	Resonance parameters: 5% in Γ_n; 10% in Γ_γ.	Harvey (Progress in Nuclear Energy, Series I, Vol. 2, p. 51) summarizes data of Pilcher '55 and McCallum, '57; 14 resonances between 5.5 and 384 ev. are known, but not to detail desired.

Table 5 - Fissile and Neighboring Nuclei

Iso-tope	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
U^{238}	$\sigma_{n,\gamma}(E)$	0.5 kev.-7 mev.	5%, or at worst 10%.	Corge et al (Saclay, '61): Up to 2 kev. Newson (B.A.P.S. 2, 218, '57): 25-220 mev. Hanna (J.N.E. 8, 197, '59): 30 - 3000 kev. Diven (P.R. 120, 556, '60): 175 - 1000 kev. Barry (AWRE, '61) is doing near 150 kev.
Pu^{238}	$\sigma_{n,f}(E)$	0.1 - 10 mev.	5%, or at worst 10%.	Butler (ANL) (WASH-1039, '62) is doing for 0.2 - 1.4 mev.
Pu^{238}	$\bar{\nu}(E)$	One point below 10 mev.	5%, or at worst 10%.	
Pu^{239}	η	0.025 ev.	0.5%, or at worst 1%.	Moore (MTR) plans to do.
Pu^{239}	$\eta(E)$	0.025-10 ev.	3%, or at worst 5%, near resonance	Leonard (RPI Symposium, '61) summarizes data up to 0.45 ev. Bollinger (ORNL-2309, '56): Up to 60 ev. Farley (J.N.E. 3, 33, '56): Up to 60 ev.

Table 5 - Fissile and Neighboring Nuclei

Iso-tope	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Pu^{239}	$\sigma_{n,f}(E)$	0.5 - 50 kev.	3%.	
Pu^{239}	$\alpha(E)$ or $\sigma_{n,\gamma}(E)$	0.5 - 150 kev.	?	de Saussure, Weston (ORNL): 5 - 1000 kev.
Pu^{239}	$\alpha(E)$ or $\sigma_{n,\gamma}(E)$	150 - 1000 kev.	η to 3%, or at worst 5%, near resonances.	Hopkins, Diven (N.S.E. 12, 169,'62): 30 - 1000 kev.
Pu^{239}	$\alpha(E)$ or $\sigma_{n,\gamma}(E)$	1 - 3 mev.	η to 5%.	
Pu^{240}	$\alpha(E)$ or $\sigma_{n,\gamma}(E)$	0.15 - 7 mev.	10%.	Spontaneous fission makes presently contemplated methods of measurement inadequate.
Pu^{240}	$\alpha(E)$ or $\sigma_{n,\gamma}(E)$	1 - 3 mev.	5%, or at worst 0.1, in . 10% in $\sigma_{n,\gamma}$.	
Pu^{240}	$\bar{\nu}$ (E)	$\leqslant$ 14 mev.	3%. One point only.	
Pu^{240}	$\bar{\nu}$ (E)	2.5 - 14 mev.	5%. Two points in the range.	

Table 5 - Fissile and Neighboring Nuclei

Isotope	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Pu^{241}	$\eta(E)$	0.025 - 100 ev.	3% - 5%.	
Pu^{241}	$\sigma_{n,f}(E)$	1 - 100 ev.	10%.	James (Saclay Symposium, '61): 3-20 ev. Leonard et al (HW-62727, '59): 0 - 20 ev. Watanabe et al (B.A.P.S. 7, 303, '62): 0 - 100 ev.
Pu^{241}	$\eta(E)$	100 ev. - 7 mev.	5%.	
Pu^{241}	$\eta(E)$	Above 500 ev.	5%.	Smith (ANL) (WASH-1031):0.3-6 mev.
Pu^{241}	$\sigma_{n,\gamma}(E)$	500 ev. - 14 mev.	20%.	
Pu^{242}	$\eta(E)$	Above threshold.	5%.	
Pu^{242}	$\sigma_{n,f}(E)$	1.5 - 7 mev.	15%.	Butler (P.R. 117, 305, '60): 0.2 - 17 mev. Henkel (LASL) has sample, will measure.
Pu^{242}	$\sigma_{n,\gamma}(E)$	5 kev. - 7 mev.	15%, or at worst 20%.	

Table 5 - Fissile and Neighboring Nuclei

Isotope	Cross Section	Energy	Accuracy Desired; Other Comments	Available Data, at given energies (MeV); Comments by NCSAG
Am^{242}	$\sigma_{n,f}(E)$	Epithermal		
Am^{242}	$\eta(E)$	0 - 14 mev,		

INDIVIDUALS' NAMES AND INSTITUTIONS

J. D. Anderson C. Wong	LRL
R. Avery	ANL
R.O. Bagley	ALCO
J. F. Barry	AWRE
J. Benveniste	LRL
E. P. Blizard	ORNL
R. C. Block (at Harwell for '62-'63; write Harvey)	ORNL
BNL Fast Chopper: Write H. Palevsky	BNL
T. W. Bonner (deceased; write G. C. Phillips at Rice).	Rice
N. A. Bostrom, formerly at TNC (write I. L. Morgan at TNC).	
D. Butler	ANL
M. R. Carrothers	GE Vallecitos
R. S. Caswell	NBS
L. F. Chase, Jr.	Lockheed
J. Chernick	BNL
R. Chrien	BNL
E. R. Cohen	AI
C. Corge	Saclay
L. Cranberg	LASL
E. A. Davis	Rice
R. B. Day	LASL
D. R. deBoisblanc	PPC
G. de Saussure L. W. Weston	ORNL
G. Dessauer	DP-SR
V. Donlan	ASD

H. J. Donnert	NDL
J. Dooley	ASD
R. Ehrlich	KAPL
J. M. Ferguson	NBDL
F. L. Filmore	AI
F. W. K. Firk	Harwell
D. G. Foster	Hanford
N. C. Francis	KAPL
W. R. Goad	LASL
H. Goldstein	CU or UNC
H. Haenni	Rice
J. A. Harvey	ORNL
B. C. Haywood I. M. Thorson	Chalk River
P. B. Hemmig	AEC
R. L. Henkel	LASL
J. Ingley	DOFL
A. Jain	BNL
L. Jewell	KN
M. H. Kalos	UNC
P. R. Kasten	ORNL
D. A. Kottwitz B. R. Leonard	Hanford
H. J. C. Kouts	BNL
R. O. Lane	ANL
A. S. Langsdorf	ANL
M. M. Levine	BNL
H. W. Lewis	Duke
D. A. Lind R. B. Day (Lind is at U. of Colorado).	LASL
W. B. Loewenstein	ANL
H. G. MacPherson	ORNL

R. E. Maerker	ORNL
M. S. Moore	MTR
I. L. Morgan	TNC
M. Moxon	Harwell
NDL (See Donnert)	
H. W. Newson	Duke
D. Okrent	ANL
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A. M. Perry	ORNL
J. M. Peterson	LRL
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A. Radkowsky	AEC
J. Rainwater	Columbia
J. E. Russell	RPI
A. R. Sayres	Columbia
K. K. Seth (Now at Northwestern U.)	Duke
E. F. Shrader	Case
W. Skolnik	KAPL
A. B. Smith	ANL
J. R. Smith	MTR
B. I. Spinrad	ANL
N. Stetson	AEC-SROO
J. J. Taylor	WBAPD
D. B. Thomson	LASL
J. H. Towle W. B. Gilboy	AWRE
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Vidal	Fontenay
L. D. Vincent (No longer there. Write I. L. Morgan at	TNC TNC)
R. M. Wilenzick (Now at Tulane University).	Duke
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AI: Atomics International, P.O. Box 309, Canoga Park, California.

ALCO: ALCO Products, Inc., Schenectady, New York.

ANL: Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, Illinois.

APDA: Atomic Power Development Associates, Inc., 1911 First Street, Detroit 26, Michigan.

ASD: Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

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KN: Kaman Nuclear, Colorado Springs, Colorado.

LASL: Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, New Mexico.

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ORNL: Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tenn.

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