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nuclear science and technology

Nuclear data guide for reactor neutron metrology

Part I: Activation reactions
Part II: Fission reactions

EUR 7164 EN

Parts I and II

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Subject

Please find enclosed a copy of the report
Zijp, W.L., and Baard, J.H.: "Nuclear Data Guide for Reactor Neutron Metrology. Part I: Activation reactions; Part II: Fission reactions", Report EUR 7164 EN (ECSC-EEC-EAEC, Brussels-Luxembourg, 1981).
Originally it was the intention that this report should also bear the identification number INDC(EUR)-15. I regret that this INDC number could not be printed on the report, owing to administrative reasons, out of my control.
As editor of this report, and as chairman of the Euratom Working Group on Reactor Dosimetry, I would appreciate receiving comments on the contents of this report. It is envisaged to prepare a revised and updated version after some time.

Yours sincerely,
Netherlands Energy Research Foundation ECN

Willem L Zijp

(W.L. Zijp)

Commission of the European Communities

nuclear science and technology

Nuclear data guide for reactor neutron metrology

Part I: Activation reactions (1979 edition)
Part II: Fission reactions (1979 edition) - see p. 163

W.L. Zijp and J.H. BAARD

Netherlands Energy Research Foundation (ECN)
Petten

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Parts I and II

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Part I

CONTENTS: PAGE :

List of symbols for physical quantities:

A_r	relative atomic mass of an element
$E(\beta)$	beta ray energy
$E(\gamma)$	gamma ray energy
$E(\gamma^{\pm})$	annihilation radiation
$\langle E \rangle$	average neutron energy for a neutron spectrum
g	Westcott g-factor
I	resonance integral cross section
I'	resonance integral cross section minus 1/v contribution
I.T.	isomeric transition
N_m	number of atoms per unit mass
N_v	number of atoms per unit volume
P_β	beta ray emission probability
P_γ	gamma ray emission probability
$\Sigma P\beta$	sum of omitted beta ray emission probabilities
$\Sigma P\gamma$	sum of omitted gamma ray emission probabilities
s_o	reduced Westcott s factor
$T_{\frac{1}{2}}$	half-life
$\langle u \rangle$	average lethargy for a neutron spectrum
$\langle v \rangle$	average neutron speed for a neutron spectrum
λ	decay constant
ρ	mass density
σ_o	thermal cross section for E = 0.0253 eV
σ_{act}	activation cross section
σ_c	calculated cross section
$\langle \sigma \rangle_c$	calculated cross section averaged over a fission neutron spectrum
σ_f	fission cross section for E = 0.0253 eV
$\langle \sigma \rangle^f$	cross section averaged over a fission neutron spectrum
σ_m	measured cross section
$\langle \sigma \rangle_m$	measured cross section averaged over a fission neutron spectrum
$\sigma(E)$	energy dependent cross section
$\phi(Co)$	equivalent fission flux density for the reaction $^{59}Co(n,\gamma)^{60}Co$
$\phi(Fe)$	equivalent fission flux density for the reaction $^{54}Fe(n,p)^{54}Mn$
$\phi(Ni)$	equivalent fission flux density for the reaction $^{58}Ni(n,p)^{58}Co$

Preface:

This document was prepared within the framework of the activities of the subgroup "Nuclear Data" of the Euratom Working Group on Reactor Dosimetry (EWGRD). This subgroup has the following aims:

a. Preparation of recommendations to the EWGRD to apply certain neutron detection reactions for specified purposes;
b. Preparation of recommendations to the EWGRD to apply particular energy dependent cross section data (from a specific file), so that each laboratory in the Community uses the same data sets (where necessary parallel to own preferred data sets);
c. Preparation of recommendations to the EWGRD to apply specified nuclear data (decay schemes, half-lives, fission yields, etc.).
d. Preparation of recommendations to the EWGRD, to apply specified fission product yields.

A previous document, edition 1977 (ECN-37), was prepared according to the decision of the EWGRD on June 1977. Since then a few comments from EWGRD members and also some more evaluated data have been received. According to the decisions of the Working Group on May, 1978, the present document should be considered as an official recommendation by the EGWRD. However, the title of the document does not refer to a recommendation, but to a "guide". It is hoped that within the European Community, all reactor neutron metrologists will follow this guide.

It is expected that this guide has to be updated after one or two years, implying an improvement and extension of the nuclear data relevant to reactor radiation measurements.

Where appropriate this guide gives numerical data from a few preferred information sources which are listed below.

List of preferred general references:

quantity of interest	sources	reference code
relative atomic mass	Holden	Ho79
mass density melting point	Handbook of Physics and Chemistry (59th edition)	We79
level schemes	Martin, Nuclear Data Sheets	Ma76 various authors
decay data: ($T_{\frac{1}{2}}$, E_β, E_γ, etc.)	Chart of Nuclides Kocher ENSDF (MEDLIST)	Wa77 Ko77 MED78
σ_o	BNL-325	Mu73
$\langle\sigma\rangle_f$	Fabry	Fa77, Fa78
$\sigma(E)$	ENDF/B-IV	Ma75

The numerical data are preferably presented in units of the International System of Units (S.I.), except the energy data which are expressed in units of MeV and keV.The S.I. implies that the cross section values are expressed in the unit m^2 or in a suitable recognized submultiple like the fm^2. Note that

$$\boxed{\begin{array}{l} 1 \text{ barn} = 10^{-28} m^2 = 100 \text{ fm}^2 \\ 1 \text{ fm}^2 = 10^{-30} m^2 = 0.01 \text{ barn} = 10 \text{ millibarn} \end{array}}$$

There has been some opposition against the replacement of the unit barn by the S.I. unit fm^2. This fm^2 unit was chosen in the 1977 edition, since the Council Directive of the CEC forbade the use of the barn with the end of 1979. This directive seems not to be based on a recommendation of international bodies active in the field of nuclear data.
The International Nuclear Data Committee, various national and regional nuclear data committees, and the Meeting of the Nuclear Reaction Data Centers, have issued recommendations to continue the usage of the unit barn. However, for pure practical reasons, it was felt convenient not to change too many units in the contents of this guide, going from the 1977 edition to the 1979 edition. In some new text parts the units barn and fm^2 are used on equal footing.
When a long half-life is expressed in years, one should note that in general a tropical year is meant. This implies that for 1 tropical year:

$$\boxed{1 \text{ a} = 365.242\ 20 \text{ d} = 31\ 556\ 926 \text{ s} \ |\text{ISO75}|}\ .$$

For convenience of the user the data are grouped per reaction of interest; these reactions are presented in order of increasing photon number (Z) of the target element, and equal for Z in order of increasing nucleon number (A=Z+N) of the target nuclide of the detection reaction.
Furthermore the principle is followed that where possible each numerical value is referenced.
The uncertainties quoted are those from the original literature sources. In this respect the following notation by Martin |Ma76| was followed:

$$3.624(12) \text{ means } \begin{cases} \text{recommended value} & 3.624 \\ \text{uncertainty} & 0.012 \end{cases}$$

The uncertainties quoted in the various references are assumed to be standard deviations (1σ).

With respect to the isotopic composition data, it is worthwhile mentioning that, according to a recent international recommendation, the expression "atom percent" should be replaced by "mole fraction".
The mole fraction of isotope i (symbol: x_i) is defined by

$$x_i = n_i / \sum_j n_j ,$$

where n_i is the number of atoms of isotope i, and where the summation is extended over all naturally occurring isotopes.

In the past one sometimes expressed the isotopic composition in terms of a "weight percent". This term should now be replaced by "mass fraction". The mass fraction of isotope i (symbol: w_i) is defined by

$$w_i = m_i / \sum_j m_j ,$$

where m_i is the mass of atoms of isotope i.

For the case of a radioactive parent (p) feeding a radioactive daughter (d) in a fraction (f) of the parent decays, the ratio of the daughter activity to that of the parent at time (t) is given by

$$\frac{f . T_{1/2}(p)}{T_{(1/2)}(p) - T_{1/2}(d)} \left[1 - e^{-(\lambda_d - \lambda_p) t}\right] , \qquad (1)$$

where $T_{1/2}(p)$ and $T_{1/2}(d)$ are the half-lives, and λ_p and λ_d are the decay constants ($\lambda = \ln 2/T_{1/2}$) of the parent and daughter, respectively. The activity of the daughter is assumed to be zero at time $t = 0$. For cases in which the daughter is short-lived compared with the parent, the parent-daughter activity ratio approaches a constant value with time. For a time large compared with $1/(\lambda_d - \lambda_p)$, Eq. (1) reduces to

$$\frac{f . T_{1/2}(p)}{T_{1/2}(p) - T_{1/2}(d)} . \qquad (2)$$

For example, ^{99}Mo decays to $^{99}Tc^m$ (6.02 h) with $T_{1/2}(p) = 66.0(2)$ h, $T_{1/2}(d) = 6.02(3)$ h, and $f = 0.8752(18)$. For large t ($t > 10$ $T_{1/2}(d)$ is sufficient here), the ratio of $^{99}Tc^m$ activity to that of ^{99}Mo is $(0.8752(18)).(1.1004(4)) = 0.9631(20)$. Thus, to correctly account for all radiations from a ^{99}Mo source, the radiations from $^{99}Tc^m$ (6.02 h) should be multiplied by 0.9631(20) and combined with those from ^{99}Mo.

In some cases, where the decay schemes of product nuclides are rather complex, energy levels and radiation transitions may not have been indicated in all completeness. As a general rule the decay schemes show only transitions with abundances larger than 1%, while the beta and gamma transitions are only listed when their abundances are larger than 0.1%.

For reasons of comparison also values for the 2200 m/s cross section were derived from differential data sets by multiplying the average cross section over a Maxwellian neutron spectrum (characterized by T = 239 K) by $2/\sqrt{\pi} = 1.128$. This value is the ratio of the cross section at the average and at the most probable speed in a Maxwellian neutron spectrum for a material with a 1/v cross section shape. Therefore the values derived in this way should be denoted as $g.\sigma_0$, when the Westcott convention is used.
Unless otherwise specified, the values for the cross sections averaged over a fission neutron spectrum have been calculated using the Watt representation for the ^{235}U spectrum.
Lines where numerical data are different from the previous (1977) edition, are indicated with the symbol "+" in the margin.
It is hoped that the next edition can refer to evaluated energy dependent cross section data, which in the near future will become available in the form as the ENDF/B-V dosimetry file, and the International Reactor Dosimetry File (IRDF).

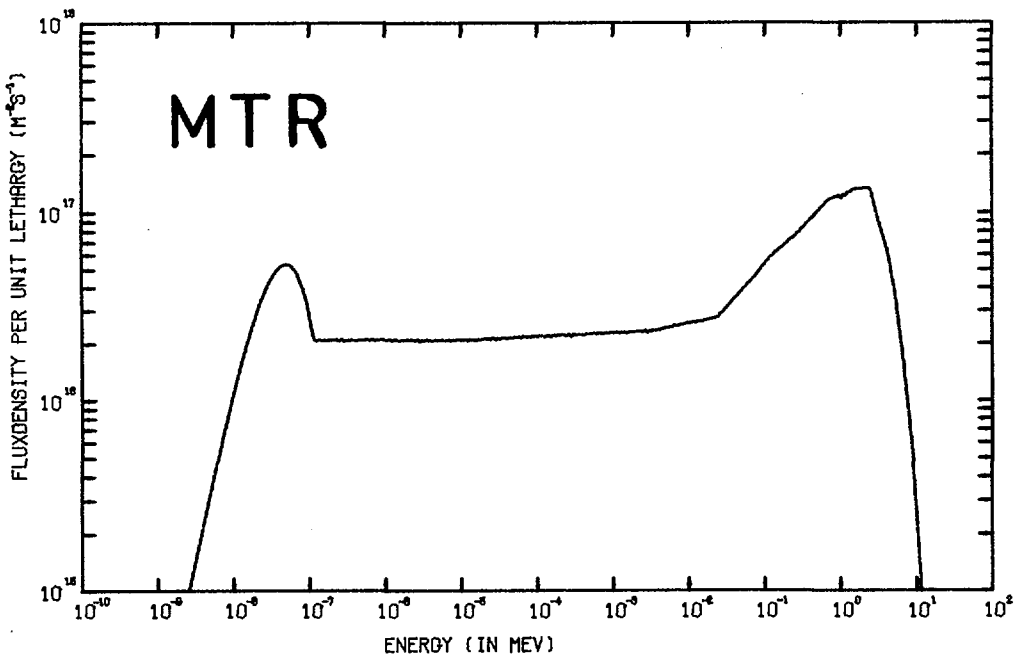
For (nearly) all detection reactions three figures are presented :

1. a figure showing the cross section as function of energy. These plots are consistent with the cross section library DOSCROS77 |Zij77|. The energy scale is taken linear for threshold reactions, and logarithmic for radiative capture reactions. The cross section scale is always logarithmic.

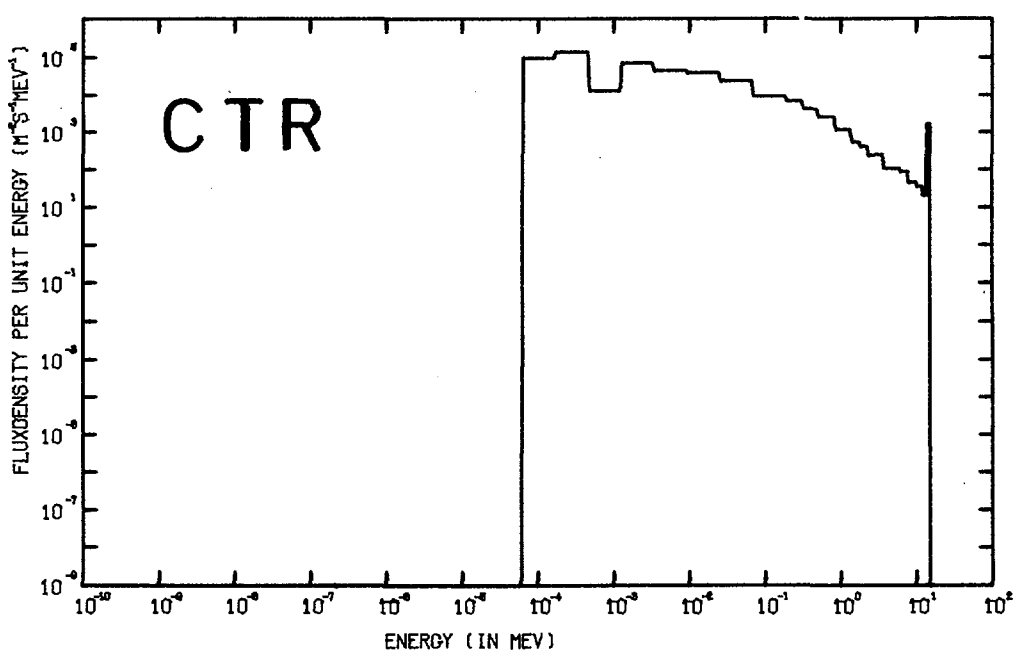
2. two figures showing the energy dependence of the response function which is defined as the integral of the energy dependent reaction cross section and the flux density per unit energy as a function of energy. The response function is presented in this report as the response per unit lethargy. The energy scale is linear or logarithmic as under 1. The response functions have been normalised to unit integral, i.e. $\int\sigma(E).\phi_E(E)dE = 1$ or $\int\sigma(u).\phi_u(u)\ du = 1$.
Two response plots are given for all reactions present in the DOSCROS77 library, one for a light water reactor, and one for a CTR TOKAMAK neutron spectrum. The light water neutron spectrum applies to an experiment position in the middle of the fuel region of the High Flux Reactor (HFR) at Petten. The neutron spectrum used has been calculated by means of

the diffusion code TEDDI-M for HFR position E5.
The high energy region has been smoothed.
The CTR TOKAMAK neutron spectrum is obtained from |Di79|.
The plots are included for illustration purposes only.

The reference flux density spectra are shown below.



HFR SPECTRUM.



CTR SPECTRUM (TOKAMAK) REF |Di79|

3. The plots are accompanied with energy ranges of response.
   90 per cent range means 5 per cent of the response and 5 per cent above this range.
   A median is calculated so that the responses below and above these ranges are equal.
   The CTR spectrum was obtained from |Di79|, the fission neutron spectra ^{252}Cf and ^{235}U are described by Grundl and Eisenhauer |Gr75|, |Gr77|, the CFRMF data come from Rogers et al. |Ro78|, the ΣΣ data come from Fabry et al. |Fa75|, the MTR spectrum is a spectrum for an experiment position in the middle of the fuel region of the High Flux Reactor at Petten.

A few specific subjects have been considered in appendices.
Appendix 1 gives attention to the role of the ENDF/B-IV dosimetry file, and the classification of the detection reaction in two categories.
Appendix 2 reviews the present status of the fission spectrum representation.
Appendix 3 considers the quality of the integral cross section data. Some tables give a comparison between measured integral cross sections, and integral values calculated using evaluated differential cross section sets.
Appendix 4 presents comparisons of measured and calculated values for the following types of cross sections : the 2200 m/s cross section, the resonance integral cross section, and the cross section averaged over a fission neutron spectrum.
Appendix 5 compares the influence of various representations of a fission neutron spectrum on the average fission neutron spectrum.
Appendix 6 lists some data for radionuclides which can serve as gamma ray spectrometry standards.
Appendix 7 lists the characteristics of the neutron spectra which are applied for the response functions.
Appendix 8 presents values for the effective threshold energy for a series of threshold reactions and some reference neutron spectra.

All people interested in reactor radiation measurements are invited to give their comments on the contents of this report.

Thanks are due to all persons who supplied comments on the previous edition. Especially the helpful contributions of W. Bambynek (JRC, BCMN, Geel, Belgium), and K. Debertin (Physikalisch-Technische Bundesanstalt, Braunschweig, Federal Republic of Germany) should be mentioned.

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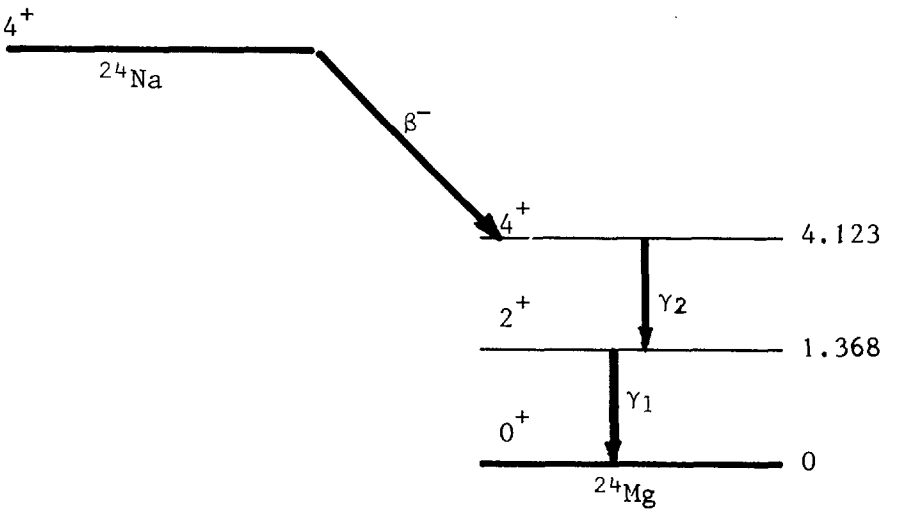
^{23}Na (n,γ) ^{24}Na

Material constants

Relative atomic mass of element	: A_r(Na)	= 22.98977(1)	|Ho79|
Mass density	: ρ	= 0.971 $Mg.m^{-3}$	|We79|
Melting point	: T	= 370.96 K = 97.81(3) °C	
Number of atoms per unit mass	: N_m	= $26.20\times10^{24}kg^{-1}$	
Number of atoms per unit volume	: N_v	= $25.44\times10^{27}m^{-3}$	
Isotopic mole fraction	: x(^{23}Na)	= 100%	|Ho79|

Disintegration scheme



Disintegration data |MED78|

\+ ^{24}Na: half-life = 15.00 (4) h

λ = $12.836\times10^{-6}s^{-1}$

\+ E(β⁻) max 1390.2(7) keV

\+ av 553.9(4) keV (99.935(4)%)

3 weak β's omitted (ΣPβ = 0.07%)

E(γ_1) 1368.53(5) (100%)

E(γ_2) 2754.09(5) (99.863(5)%)

4 weak γ's omitted (ΣPγ = 0.06%)

Activities induced in sodium

$^{23}Na(n,\gamma)^{24}Na$

+ $T_{\frac{1}{2}}$ = 15.00 h |MED78| σ_{act} = 53.0(5) fm^2 |Mu73|

I = 31.1(10) fm^2 |Mu73| I' = 7.5(10) fm^2 |Ba63|

g value Westcott conv. 1

s_0 value Westcott conv. 0.1597

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : $g.\sigma_0$ = 53.66 fm^2 } |Zij77|

I = 33.15 fm^2

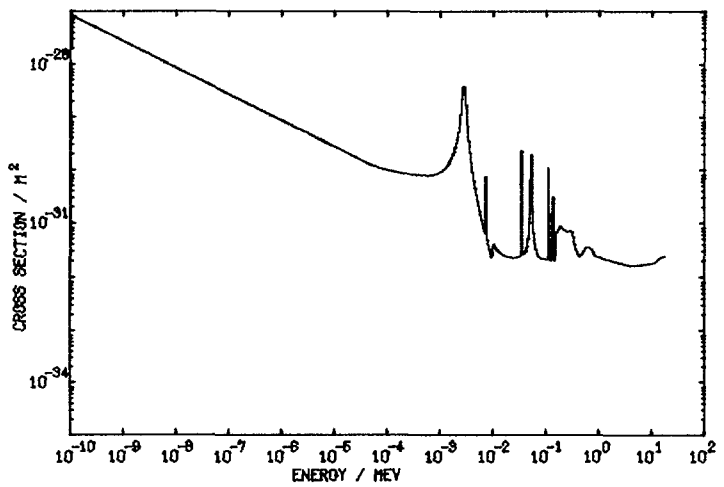
Response data

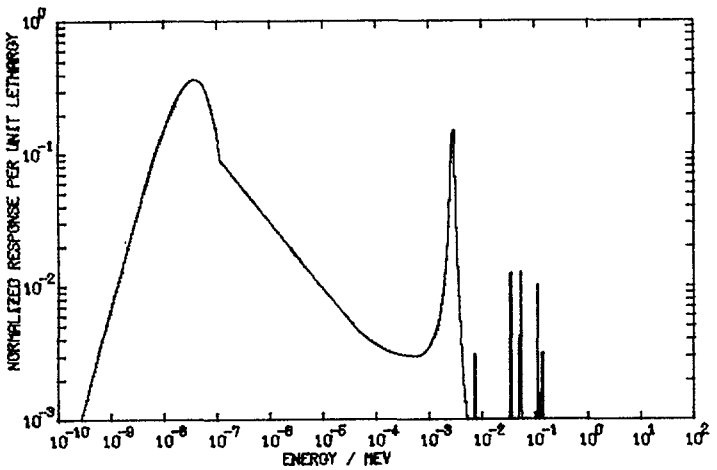
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: NA23(N,G)NA24

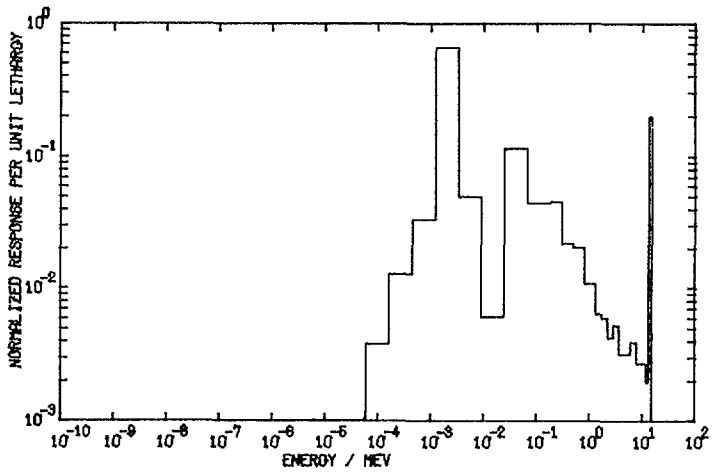
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.2E-03	3.0E-01	1.2E-03	2.5E-02	1.2E-03	1.2E-03	1.2E-03
252CF	5.0E-02	4.7E+00	2.2E-01	2.4E+00	5.0E-01	1.5E+00	9.2E-01
235U	3.4E-02	4.3E+00	1.9E-01	2.2E+00	4.3E-01	1.3E+00	8.0E-01
CFRMF	1.3E-03	5.3E-01	2.6E-03	1.1E-01	2.8E-03	4.0E-03	2.8E-03
SIG.SIG.	1.5E-03	6.9E-01	2.6E-03	1.6E-01	2.8E-03	5.3E-02	3.2E-03
MTR	5.0E-09	1.2E-04	1.5E-08	1.5E-07	2.6E-08	6.0E-08	3.8E-08

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{24}Mg\ (n,p)\ ^{24}Na$

Material constants

Relative atomic mass of element	$A_r(Mg)$	= 24.305(1)	|Ho79|, |We79|
Mass density	ρ	= 1.738 $Mg.m^{-3}$	|We79|
Melting point	T	= 921.95 K = 648.8(5) °C	|We79|
Number of atoms per unit mass	N_m	= $24.779\times10^{24} kg^{-1}$	
N8mber of atoms per unit volume	N_v	= $43.066\times10^{27} m^{-3}$	
Isotopic mole fractions	$x(^{24}Mg)$	= 78.99(1) %	|Ho79|
	$x(^{25}Mg)$	= 10.00(1) %	|Ho79|
	$x(^{26}Mg)$	= 11.01(1) %	|Ho79|

Disintegration scheme and - data

See the reaction $^{23}Na(n,\gamma)^{24}Na$

Activities induced in magnesium

$^{24}Mg(n,p)^{24}Na$; $T_{\frac{1}{2}}$ = 15.00 h	|MED78|	;$\langle\sigma\rangle$=1.53(9) mb=0.153 fm^2	|Ca74|
$^{25}Mg(n,p)^{25}Na$; $T_{\frac{1}{2}}$ = 60 s	|Wa77|	;$\langle\sigma\rangle$=3.2(16) mb=0.32 fm^2	|Ca74|
$^{24}Mg(n,\gamma)^{25}Mg$; stable		;σ_0 =0.052(7) b=5.2 fm^2	|Mu73|
		; I =0.030(4) b=3.0 fm^2	|Mu73|
$^{25}Mg(n,\gamma)^{26}Mg$; stable		;σ_0 =0.180(32)b=18 fm^2	|Mu73|
		; I =0.111(20)b=11.1 fm^2	|Mu73|
$^{26}Mg(n,\gamma)^{27}Mg$; $T_{\frac{1}{2}}$ = 9.45 min	|Wa77|	;σ_0 =0.0382(8)b=3.82 fm^2	|Mu73|
		; I =0.025(1) b=2.5 fm^2	|Mu73|

Evaluated cross section data

620 group data : |Ei74|, |Zij77|

Integral data : for a ^{235}U fission spectrum :$\langle\sigma\rangle_c$=1.498 mb =0.1498 fm^2 } |Zij77|

$\langle\sigma\rangle_m$=1.480(82) mb =0.148 fm^2 } |Fa78|

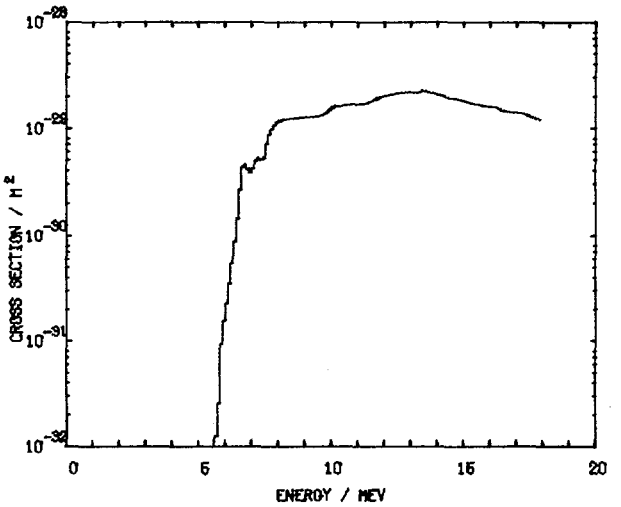
Response data

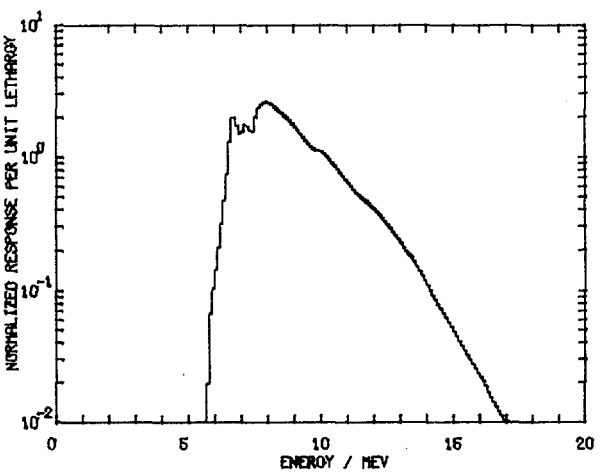
See next page.

RESPONSE DATA FOR THE REACTION: MG24(N,P)NA24

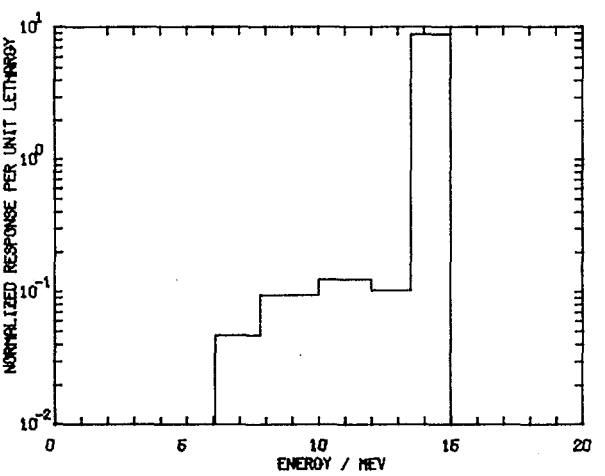
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.0E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	6.5E+00	1.2E+01	7.1E+00	9.8E+00	7.7E+00	8.8E+00	8.2E+00
235U	6.5E+00	1.2E+01	7.0E+00	9.4E+00	7.6E+00	8.6E+00	8.0E+00
CFRMF	6.5E+00	1.2E+01	7.1E+00	9.7E+00	7.7E+00	8.7E+00	8.1E+00
SIG.SIG.	6.5E+00	1.2E+01	7.0E+00	9.4E+00	7.6E+00	8.6E+00	8.0E+00
MTR	6.5E+00	1.2E+01	7.1E+00	9.7E+00	7.7E+00	8.8E+00	8.2E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{27}Al(n,\alpha)^{24}Na$

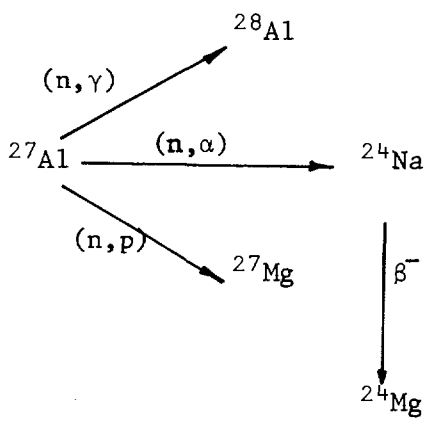
Material constants

See the reaction $^{27}Al(n,p)^{27}Mg$.

Disintegration scheme and -data

See the reaction $^{23}Na(n,\gamma)^{24}Na$.

Reaction of interest



Activities induced in aluminium

See the reaction $^{27}Al(n,p)^{27}Mg$.

Evaluated cross section data

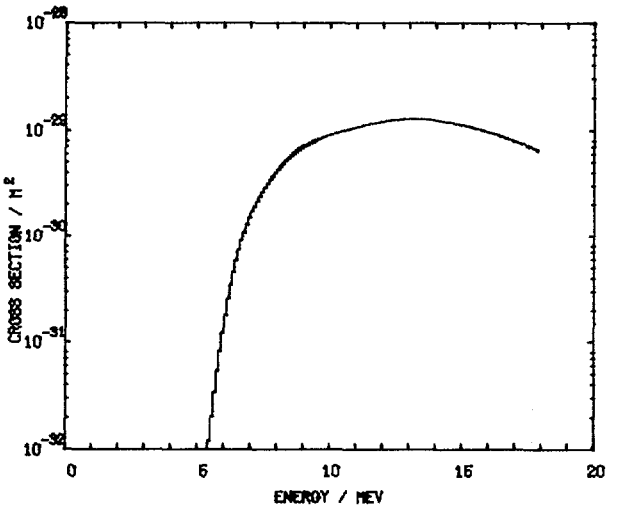
620 group data : |Ma75|, |Zij77 |

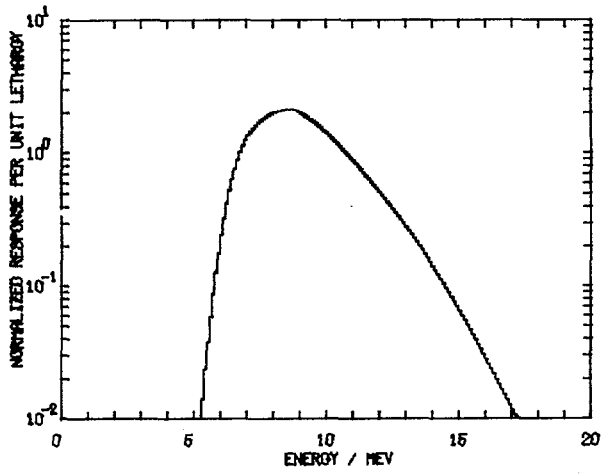
Integral data : $\langle\sigma\rangle^f = 0.06843$ fm^2 |Zij76 |, |Zij77|

RESPONSE DATA FOR THE REACTION: AL27(N,A)NA24

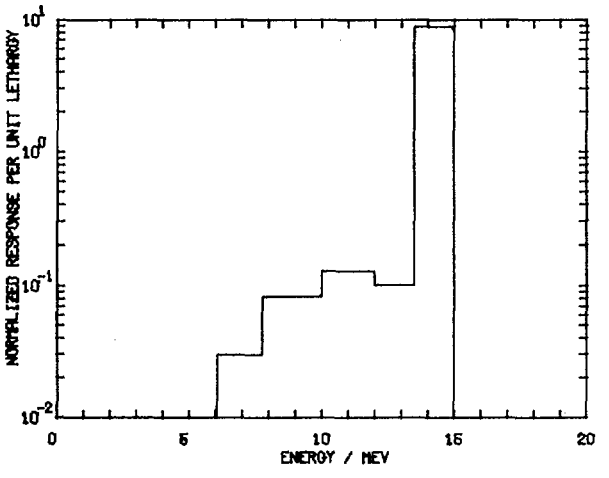
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.0E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	6.5E+00	1.2E+01	7.4E+00	1.0E+01	8.0E+00	9.3E+00	8.6E+00
235U	6.4E+00	1.2E+01	7.2E+00	9.9E+00	7.8E+00	9.0E+00	8.4E+00
CFRMF	6.5E+00	1.2E+01	7.3E+00	1.0E+01	7.9E+00	9.2E+00	8.5E+00
SIG.SIG.	6.4E+00	1.2E+01	7.2E+00	9.9E+00	7.8E+00	9.0E+00	8.4E+00
MTR	6.5E+00	1.2E+01	7.3E+00	1.0E+01	8.0E+00	9.2E+00	8.6E+00

ALL ENERGY VALUES IN MEV.





MTR



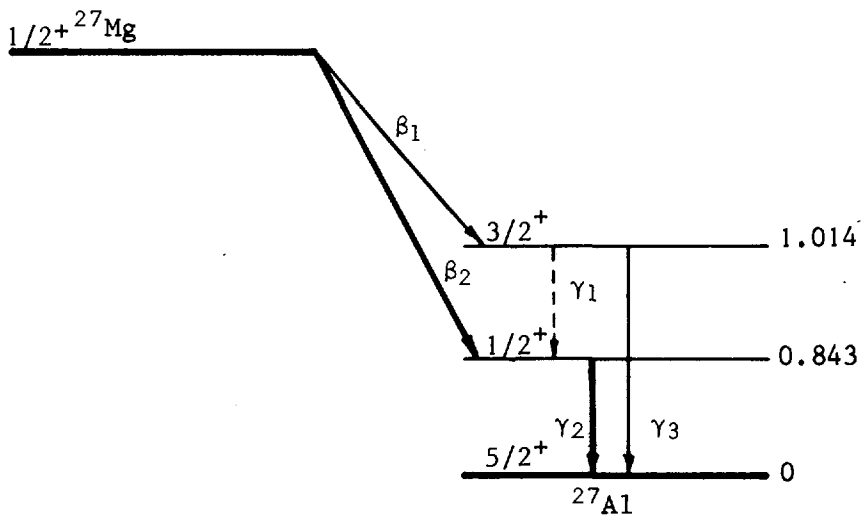
CTR

^{27}Al (n,p) ^{27}Mg

Material constants

Relative atomic mass of element	: A_r(Al)	= 26.98154(1)	|Ho79|
Mass density	: ρ	= 2.6989 $Mg.m^{-3}$	|We79|
Melting point	: T	= 933.52 K = 660.37°C	|We79|
Number of atoms per unit mass	: N_m	= $22.32\times10^{24}kg^{-1}$	
Number of atoms per unit volume	: N_v	= $60.24\times10^{27}m^{-3}$	
Isotopic mole fraction	: x(^{27}Al)	= 100%	|Ho79|

Disintegration scheme



Disintegration data |MED78|

^{27}Mg: half-life = 9.462(11) min

λ = $1.2209\times10^{-3}s^{-1}$

+	$E(\beta_1^-)$	max	1594.8(12)	keV	
+		av	645.8(5)	keV	(29.0(4)%)
+	$E(\beta_2^-)$	max	1765.5(12)	keV	
+		av	724.3(6)	keV	(71.0(4)%)
+	Total β^-	av	701.5(6)	keV	(100.0(6)%)
	$E(\gamma_1)$		170.686(15)	keV	(0.80(10)%)
	$E(\gamma_2)$		843.76(3)	keV	(71.8(4)%)
	$E(\gamma_3)$		1014.44(4)	keV	(28.0(4)%)

Activities induced in aluminium

$^{27}Al(n,p)^{27}Mg$

$T_{\frac{1}{2}}$ = 9.462 min |MED78| $\langle\sigma\rangle$=0.386(25) fm^2 |Fa77|

$^{27}Al(n,\gamma)^{28}Al$

+ $T_{\frac{1}{2}}$ = 2.240 min |Ma76| σ_{act} = 23.0(3) fm^2 |Mu73|

$^{27}Al(n,\alpha)^{24}Na$

+ $T_{\frac{1}{2}}$ = 15.00(4)h |MED78| $\langle\sigma\rangle$ = 0.0705(40) fm^2 |Fa77|

Evaluated cross section data

620 group data : |Ma75|, |Zij77 |

Integral data : $\langle\sigma\rangle^f$ = 0.41 fm^2 | Zij76 |, |Zij77|

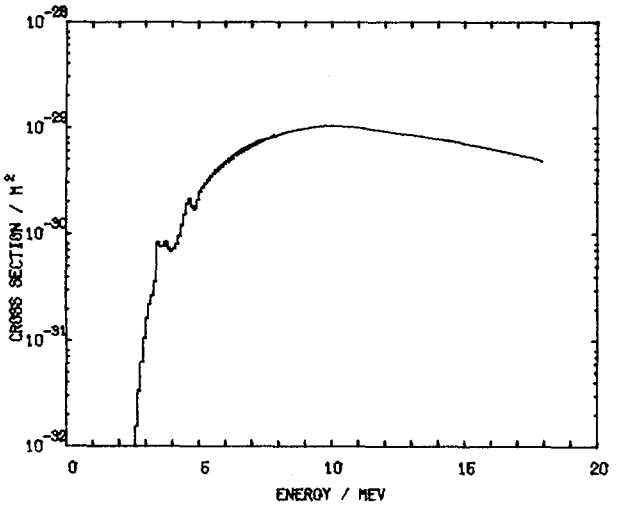
Response data

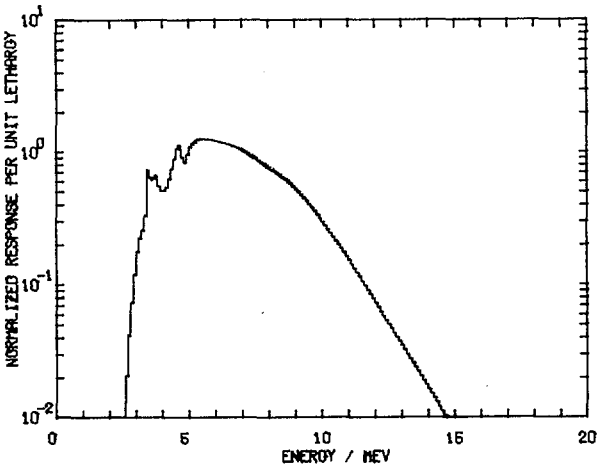
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: AL27(N,P)MG27

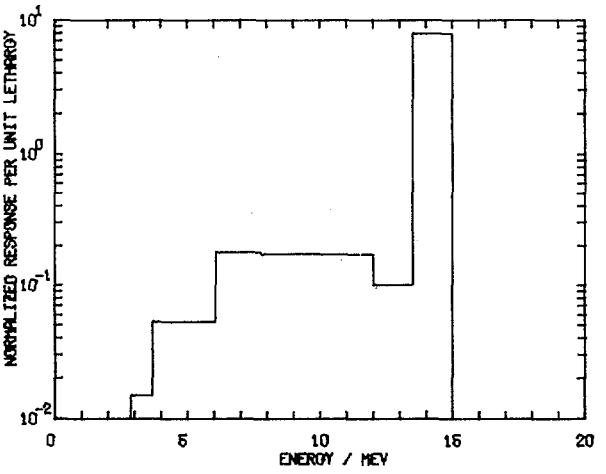
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	6.1E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	3.5E+00	9.8E+00	4.5E+00	7.7E+00	5.3E+00	6.7E+00	5.9E+00
235U	3.4E+00	9.3E+00	4.4E+00	7.4E+00	5.1E+00	6.4E+00	5.7E+00
CFRMF	3.4E+00	9.6E+00	4.4E+00	7.6E+00	5.2E+00	6.6E+00	5.9E+00
SIG.SIG.	3.4E+00	9.4E+00	4.3E+00	7.4E+00	5.1E+00	6.5E+00	5.8E+00
MTR	3.4E+00	9.6E+00	4.4E+00	7.6E+00	5.1E+00	6.5E+00	5.7E+00

ALL ENERGY VALUES IN MEV.





MTR



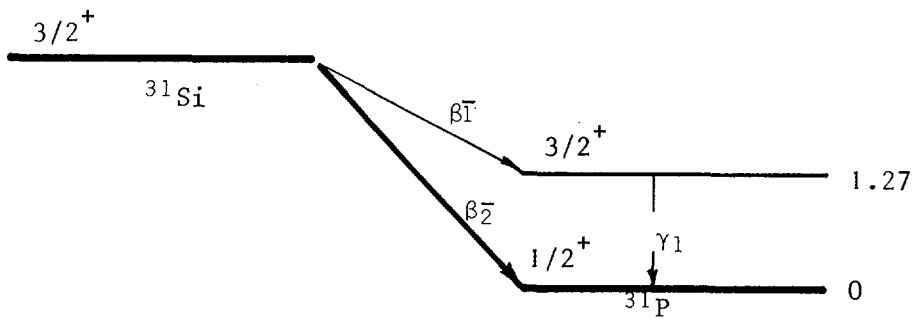
CTR

$^{31}P\ (n,p)\ ^{31}Si$

Material constants

Relative atomic mass of element	: $A_r(P)$	= 30.97376(1)	|Ho79|
Mass density	: ρ	= (white) 1.82 $Mg.m^{-3}$ *	|We79|
Melting point	: T	= 317.25 K = 44.1 °C (white)	|We79|
Number of atoms per unit mass	: N_m	= $19.44\times10^{24} kg^{-1}$	
Number of atoms per unit volume	: N_v	= $35.39\times10^{27} m^{-3}$	
Isotopic mole fraction	: $x(^{31}P)$	= 100%	|Ho79|

Disintegration scheme |En78|



Disintegration data |MED78|

^{31}Si : half-life : $T_{\frac{1}{2}}$ = 157.3 (3) min.

decay constant : λ = 73.442 x $10^{-6} s^{-1}$

$E(\beta_1^-)$	omitted			0.07 %
$E(\beta_2^-)$ max	1491.6 (11)	keV		
av	596	keV		99.93 (5) %
$E(\gamma_1)$	1.27	keV	|En78|	0.07 %

Activities induced in phosphorus

$^{31}P\ (n,\gamma)\ ^{32}P$; $T_{\frac{1}{2}}$ = 14.29(3) d|MED78|; σ_0=0.180(7) b=18.0 fm^2
I =0.08 (2) b= 8 fm^2 |Mu73|

$^{31}P\ (n,p)\ ^{31}Si$; $T_{\frac{1}{2}}$ =157.3(3) min|MED78|;$\langle\sigma\rangle$= 36(3) mb= 3.6 fm^2
$^{31}P\ (n,\alpha)\ ^{28}Al$; $T_{\frac{1}{2}}$ =2.240(1) min |Ma76|;$\langle\sigma\rangle$= 1.9(6)mb= 0.19fm^2 |Ca74|

Evaluated cross section data

620 group data : |Ma75|,|Zij77|

integral data : for a ^{235}U fission spectrum: $\langle\sigma\rangle$=33.01mb =3.301 fm^2 |Zij77|

$\langle\sigma\rangle_m$=35.5(27)mb =3.55 fm^2 |Fa78|

Remarks

* The phosphorus targets can be in different states: white, red and black phosphorus. The mass densities of red and black phosphorus are 2.20 Mg.m^{-3} and 2.25-2.69 Mg.m^{-3} |We79|, respectively.

Response data

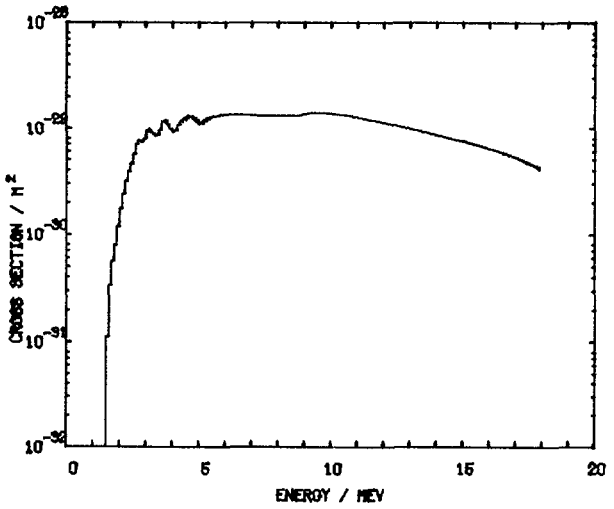
Threshold energy : E_T = 2.4 MeV

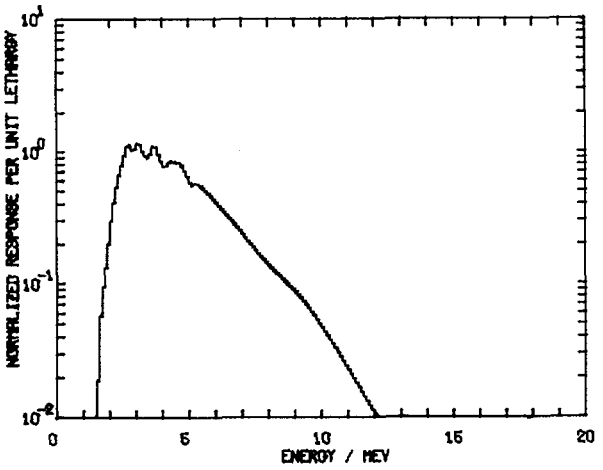
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: P31(N,P)SI31

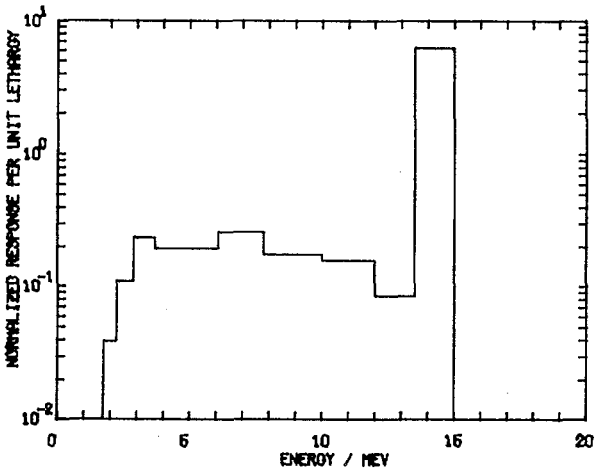
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	2.9E+00	1.4E+01	6.1E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	2.2E+00	7.4E+00	2.7E+00	5.3E+00	3.2E+00	4.4E+00	3.7E+00
235U	2.1E+00	7.0E+00	2.7E+00	5.1E+00	3.1E+00	4.2E+00	3.6E+00
CFRMF	2.1E+00	7.1E+00	2.6E+00	5.1E+00	3.0E+00	4.2E+00	3.5E+00
SIG.SIG.	2.0E+00	6.9E+00	2.6E+00	4.9E+00	2.9E+00	3.9E+00	3.4E+00
MTR	2.1E+00	7.0E+00	2.6E+00	4.9E+00	3.0E+00	4.1E+00	3.5E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{32}S\ (n,p)\ ^{32}P$

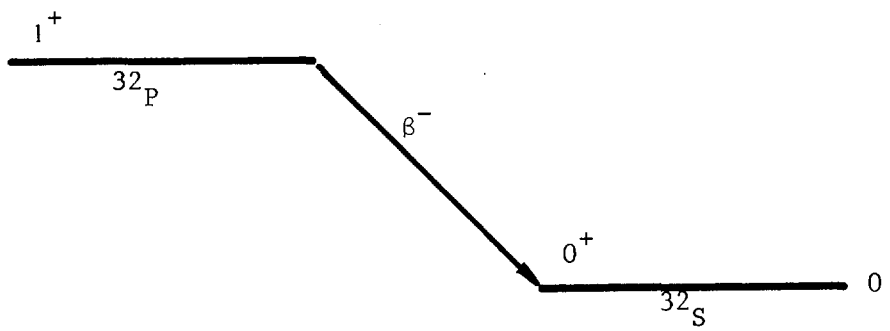
Material constants

Relative atomic mass of element:	$A_r(S)$	= 32.06(1)	|Ho79|	
		rhombic	monoclinic	
Mass density	: ρ	= 2.07	1.957 $Mg.m^{-3}$	|We79|
Melting point	: T	= 385.95	392.15 K	
		112.8	119.0 °C	
Number of atoms per unit mass	: N_m	= 18.79×10^{24}	$18.79\times10^{24}kg^{-1}$	
Number of atoms per unit volume:	N_v	= 38.89×10^{27}	$36.76\times10^{27}m^{-3}$	

Isotopic mole fractions :

$x(^{32}S)$	= 95.02(1) %	|Ho79|
$x(^{33}S)$	= 0.75(1) %	
$x(^{34}S)$	= 4.21(1) %	
$x(^{36}S)$	= 0.02(1) %	

Disintegration scheme



Disintegration data |MED78|

^{32}P : half-life : $T_{\frac{1}{2}}$ = 14.29 (3) d

decay constant : $\lambda = 5.6141\times10^{-7}s^{-1}$

$E(\beta^-)$ max 1710.4(6) keV

av 695.0(3) keV 100 %

Activities induced in sulfur

$^{32}S\ (n,p)^{32}P$; $T_{\frac{1}{2}}$ = 14.29 d	|MED78| ; $<\sigma>$ = 69(4) mb = 6.9 fm^2	|Ca74|
$^{33}S\ (n,p)^{33}P$; $T_{\frac{1}{2}}$ = 25.3 d	|Wa77| ; $<\sigma>$ = 76(15)mb = 7.6 fm^2	
$^{34}S\ (n,p)^{34}P$; $T_{\frac{1}{2}}$ = 12.4 s	|Wa77| ; $<\sigma>$ = 0.43(5)mb= 0.043 fm^2	

$^{32}S\ (n,\gamma)^{33}S$; stable		;σ_0 =53(4) fm^2	} |Mu73|
$^{36}S\ (n,\gamma)^{37}S$; $T_{\frac{1}{2}}$= 5.05 min	|Wa77|	;σ_0 =15(3) fm^2	
$^{34}S\ (n,\alpha)^{31}Si$; $T_{\frac{1}{2}}$=157.3 min	|MED78|	;$\langle\sigma\rangle$=0.22(2)fm^2	|Ca74|

Evaluated cross section data

620 group data : |Ma75| ,|Zij77|

Integral data : $\langle\sigma\rangle$ = 6.505 fm^2 |Zij77|

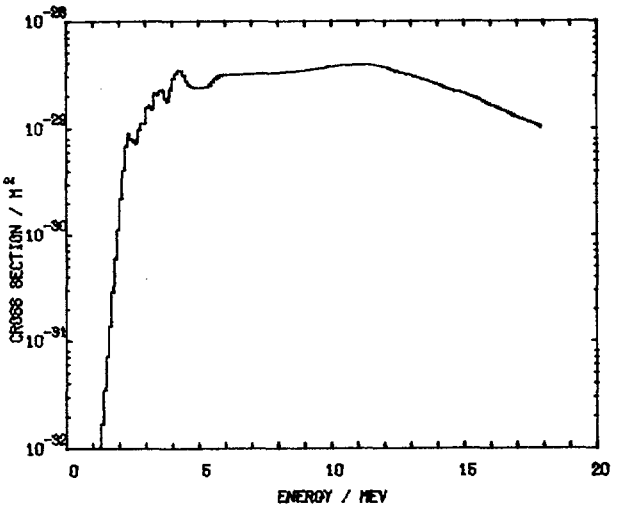
Response data

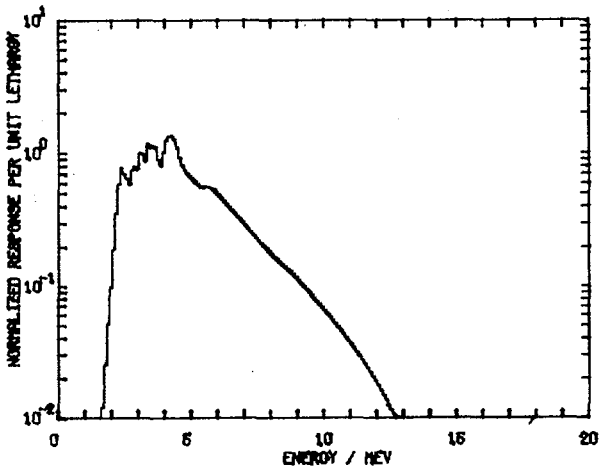
for table and figures see next page.

RESPONSE DATA FOR THE REACTION: S32(N,P)P32

SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	2.9E+00	1.4E+01	6.1E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	2.3E+00	7.8E+00	3.0E+00	5.6E+00	3.5E+00	4.5E+00	4.0E+00
235U	2.2E+00	7.3E+00	2.9E+00	5.3E+00	3.4E+00	4.4E+00	3.9E+00
CFRMF	2.2E+00	7.5E+00	2.8E+00	5.4E+00	3.3E+00	4.4E+00	3.8E+00
SIG.SIG.	2.2E+00	7.3E+00	2.7E+00	5.2E+00	3.2E+00	4.2E+00	3.7E+00
MTR	2.2E+00	7.4E+00	2.8E+00	5.2E+00	3.3E+00	4.3E+00	3.8E+00

ALL ENERGY VALUES IN MEV.





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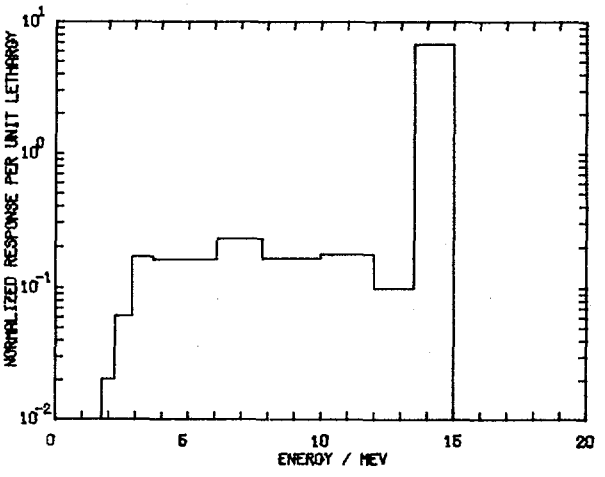


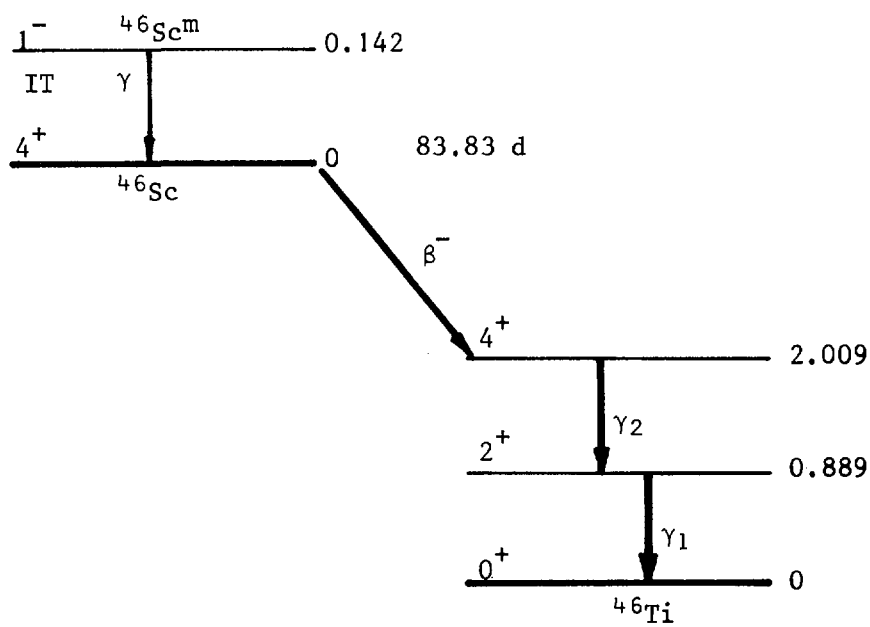
CTR

$^{45}Sc(n,\gamma)^{46}Sc$

Material constants

Relative atomic mass of element: $A_r(Sc) = 44.9559(1)$ |Ho79|,
Mass density : $\rho = 2.989\ Mg.m^{-3}$ |We79|
Melting point : $T = 1814.15\ K = 1541\ ^oC$ |We79|
Number of atoms per unit mass : $N_m = 13.40\times10^{24} kg^{-1}$
Number of atoms per unit volume: $N_v = 40.04\times10^{27} m^{-3}$
Isotopic mole fraction : $x(^{45}Sc) = 100\%$ |Wa77|

Disintegration scheme



Disintegration data |MED78|

+ $^{46}Sc^m$: half-life = 18.70(5) s
+ $\lambda = 37.067\times10^{-3} s^{-1}$
+ $E_\gamma = 142.528(3)$ keV (62.0(20)%)

+ ^{46}Sc: half-life = 83.83(2) d
+ $\lambda = 95.700\times10^{-9} s^{-1}$

+ $E(\beta^-)$ max 357.3(8) keV
+ av 112.0(3) keV (99.9964(7)%)

+ $E(\gamma_1)$ 889.25 (3) keV (99.9840(10)%)
+ $E(\gamma_2)$ 1120.51 (5) keV (99.9870(10)%

Activities induced in scandium

$^{45}Sc(n,\gamma)^{46}Sc^{m}$

+ $T_{\frac{1}{2}}$ = 18.70 s |MED78| σ_{act} = 960(100) fm^2

$^{45}Sc(n,\gamma)^{46}Sc$

$T_{\frac{1}{2}}$ = 83.83 d |MED78| σ_{act} = 1690(100)fm^2 (direct)

σ_{act} = 2650(100)fm^2 (direct+indirect)

I = 1130(100) fm^2 |Mu73|

} |Mu73|

$^{46}Sc(n,\gamma)^{47}Sc$

* $T_{\frac{1}{2}}$ = 3.351 d |MED78| σ_{act} = 800(100) fm^2 |Mu73|

$^{45}Sc(n,p)^{45}Ca$

$T_{\frac{1}{2}}$ = 163 d |Se74|

$^{45}Sc(n,\alpha)^{42}K$

$T_{\frac{1}{2}}$ = 12.36 h |Se74|

Evaluated cross section data

620 group data: |Ma75|, |Zij77 |

Integral data : $g.\sigma_0$ = 2650 fm^2 |Zij77 |

I = 1160 fm^2 |Zij77 |

*Remark

The value of 3.351(2) d |MED78| and |PTB78| for the half-life of ^{47}Sc deviates clearly from previously published evaluated data:

3.41 d |Wa77|

and 3.422(4)d |Ma76|.

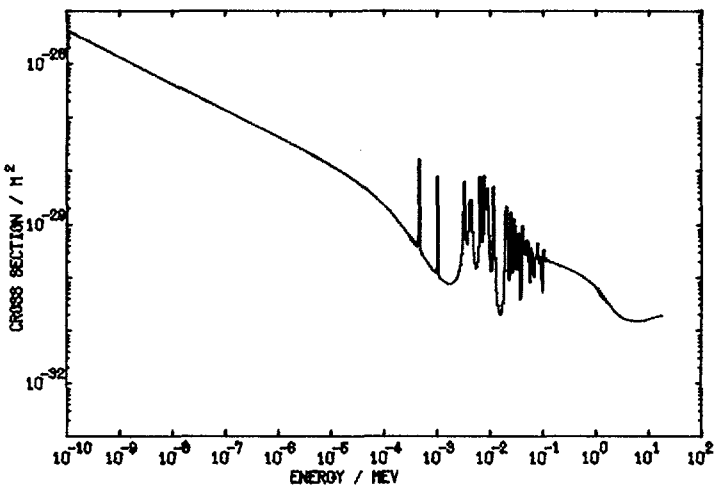
Response data

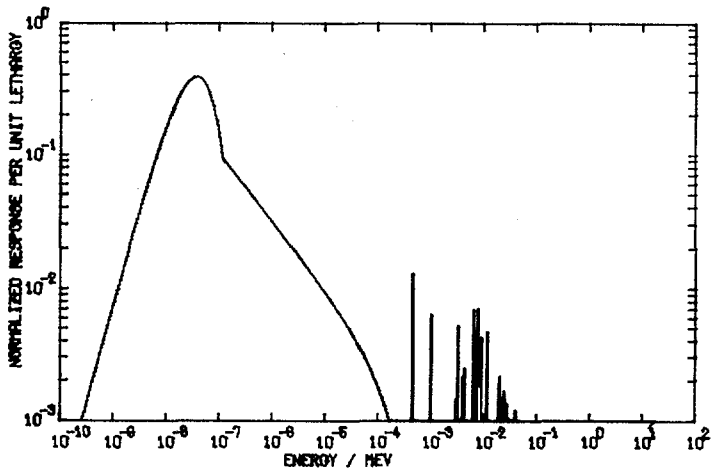
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: SC45(N,G)SC46

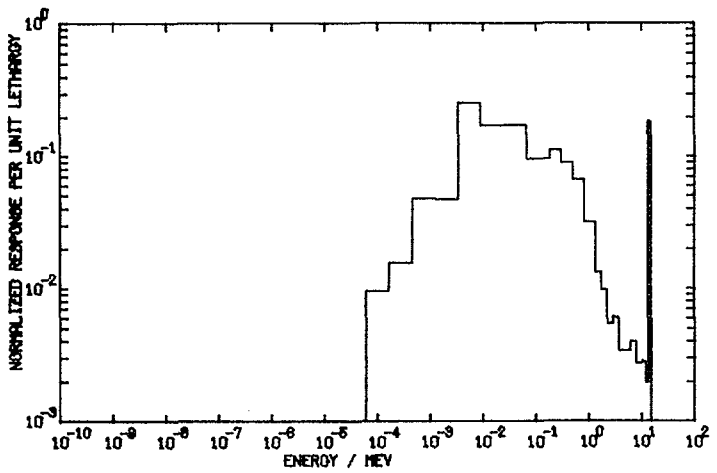
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	4.5E-04	5.0E-01	3.4E-03	6.8E-02	3.4E-03	2.5E-02	9.1E-03
252CF	5.5E-02	3.4E+00	2.6E-01	1.5E+00	4.5E-01	1.0E+00	6.6E-01
235U	4.5E-02	3.1E+00	2.3E-01	1.4E+00	4.0E-01	9.2E-01	6.3E-01
CFRMF	1.0E-03	8.0E-01	7.6E-03	3.4E-01	2.4E-02	1.6E-01	6.0E-02
SIG.SIG.	1.0E-03	8.8E-01	8.4E-03	3.6E-01	2.7E-02	1.8E-01	7.6E-02
MTR	5.0E-09	1.4E-06	1.4E-08	1.0E-07	2.4E-08	5.5E-08	3.6E-08

ALL ENERGY VALUES IN MEV.





MTR



CTR

Ti (n,x) ^{46}Sc

This reaction comprises $^{46}Ti(n,p)^{46}Sc$ and also $^{47}Ti(n,d)^{46}Sc$ and $^{47}Ti(n,n'p)^{46}Sc$.

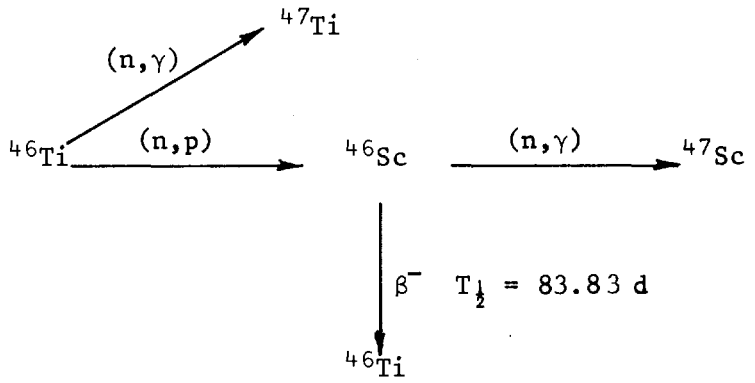
Material constants

Relative atomic mass of element	$A_r(Ti)$	= 47.90(3) |Ho79|,	|We79|
Mass density	ρ	= 4.54 $Mg.m^{-3}$	
Melting point	T	= 1933.15 K = 1660(10)°C	
Number of atoms per unit mass	N_m	= $12.57\times10^{24}kg^{-1}$	
Number of atoms per unit volume	N_v	= $57.08\times10^{27}m^{-3}$	
+ Isotopic mole fractions	$x(^{46}Ti)$	= 8.1(1) %	|Ho79|
+	$x(^{47}Ti)$	= 7.4(1) %	
	$x(^{48}Ti)$	= 73.8(1) %	
+	$x(^{49}Ti)$	= 5.4(1) %	
+	$x(^{50}Ti)$	= 5.3(1) %	

Disintegration scheme and data

See the reaction $^{45}Sc\ (n,\gamma)^{46}Sc$

Reaction of interest



Activities induced in titanium

^{46}Ti(n,γ)^{47}Ti	stable		σ_0 = 60(10) fm^2	
^{47}Ti(n,γ)^{48}Ti	stable		σ_0 = 170(20) fm^2	
^{48}Ti(n,γ)^{49}Ti	stable		σ_0 = 780(30) fm^2	|Mu73|
^{49}Ti(n,γ)^{50}Ti	stable		σ_0 = 220(30) fm^2	
^{50}Ti(n,γ)^{51}Ti	$T_{\frac{1}{2}}$ = 5.8 min	|Se74|	σ_0 = 17.9(3) fm^2	
+^{46}Ti(n,p)^{46}Sc	$T_{\frac{1}{2}}$ = 83.83 d		<σ>	
+^{47}Ti(n,n'p)^{46}Sc	$T_{\frac{1}{2}}$ = 83.83 d	|MED78|	<σ> = 1.180(75) fm^2	|Fa76|,|Fa78|
+^{47}Ti(n,d)^{46}Sc	$T_{\frac{1}{2}}$ = 83.83 d		<σ>	
+^{47}Ti(n,p)^{47}Sc	* $T_{\frac{1}{2}}$ = 3.351 d		<σ> = 1.90(14) fm^2	|Fa76|,|Fa78|
+^{48}Ti(n,p)^{48}Sc	$T_{\frac{1}{2}}$ = 43.7 h	|MED78|	<σ> = 0.0300(18) fm^2	|Fa76|,|Fa78|
^{48}Ti(n,α)^{45}Ca	$T_{\frac{1}{2}}$ = 163 d	|Se74|	<σ> = 0.0013(6) fm^2	|Ca74|
^{50}Ti(n,α)^{47}Ca	$T_{\frac{1}{2}}$ = 4.54 d	|Se74|	<σ> = 46(23) am^2	|Ca74|

Evaluated cross section data

620 group data : |Ph77|, |Zij77|

Integral data : ^{46}Ti(n,p)^{46}Sc; $\langle\sigma\rangle^f$ = 0.9920 fm^2
^{47}Ti(n,np)^{46}Sc; $\langle\sigma\rangle^f$ = 3.171×10^{-4} fm^2 } |Zij76|, |Zij77|

* See remarks at the reaction ^{45}Sc (n,γ)^{46}Sc

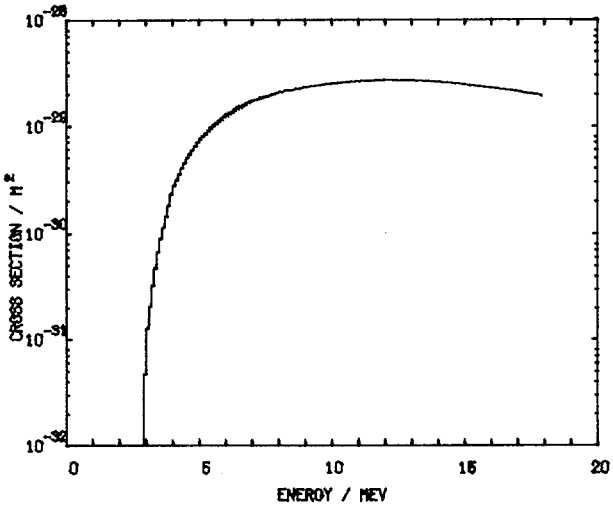
Response data

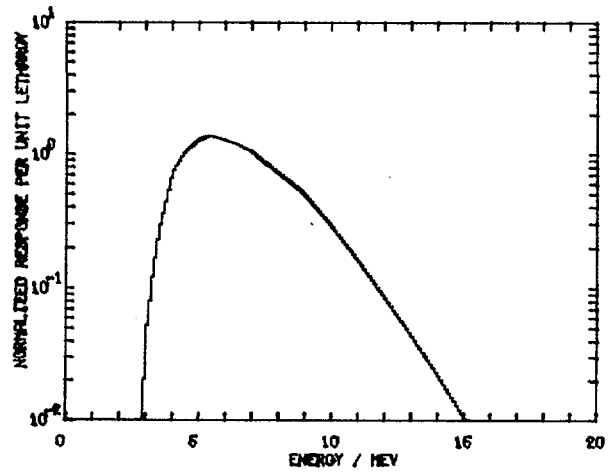
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: TI46(N,P)SC46

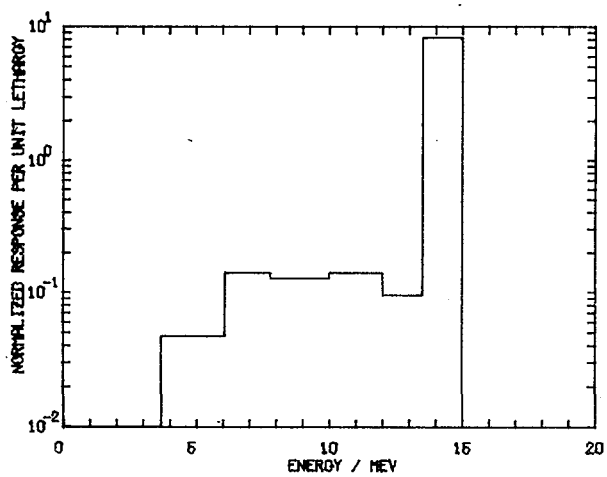
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	6.1E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	3.8E+00	9.8E+00	4.6E+00	7.6E+00	5.3E+00	6.6E+00	5.9E+00
235U	3.8E+00	9.3E+00	4.5E+00	7.3E+00	5.1E+00	6.4E+00	5.7E+00
CFRMF	3.8E+00	9.6E+00	4.6E+00	7.5E+00	5.2E+00	6.6E+00	5.8E+00
SIG.SIG.	3.7E+00	9.4E+00	4.5E+00	7.4E+00	5.2E+00	6.5E+00	5.8E+00
MTR	3.7E+00	9.7E+00	4.5E+00	7.5E+00	5.1E+00	6.5E+00	5.7E+00

ALL ENERGY VALUES IN MEV.





MTR

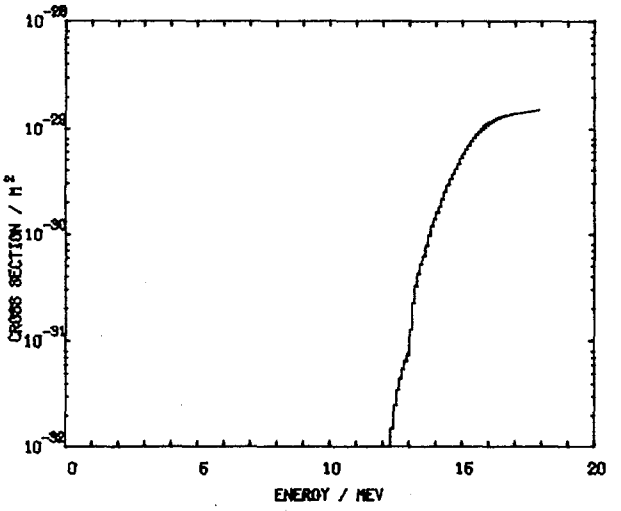


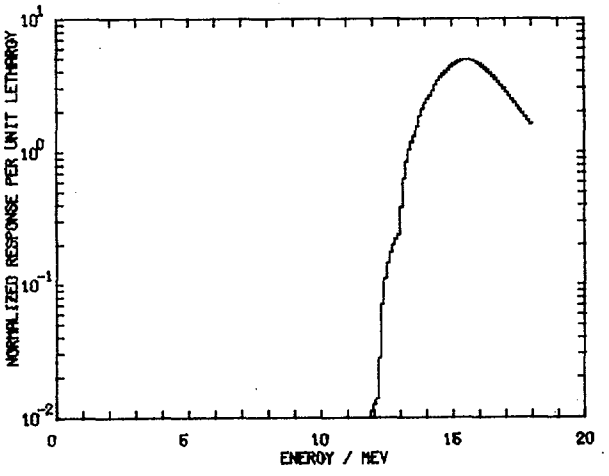
CTR

RESPONSE DATA FOR THE REACTION: TI47(N,NP)SC46

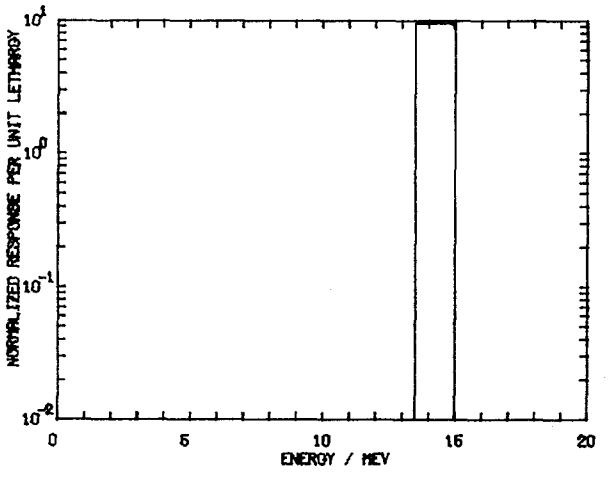
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.4E+01	1.8E+01	1.5E+01	1.7E+01	1.5E+01	1.6E+01	1.6E+01
235U	1.4E+01	1.7E+01	1.4E+01	1.7E+01	1.5E+01	1.6E+01	1.5E+01
CFRMF	1.4E+01	1.8E+01	1.5E+01	1.7E+01	1.5E+01	1.6E+01	1.6E+01
SIG.SIG.	1.4E+01	1.8E+01	1.5E+01	1.7E+01	1.5E+01	1.6E+01	1.6E+01
MTR	1.4E+01	1.8E+01	1.4E+01	1.7E+01	1.5E+01	1.6E+01	1.6E+01

ALL ENERGY VALUES IN MEV.





MTR

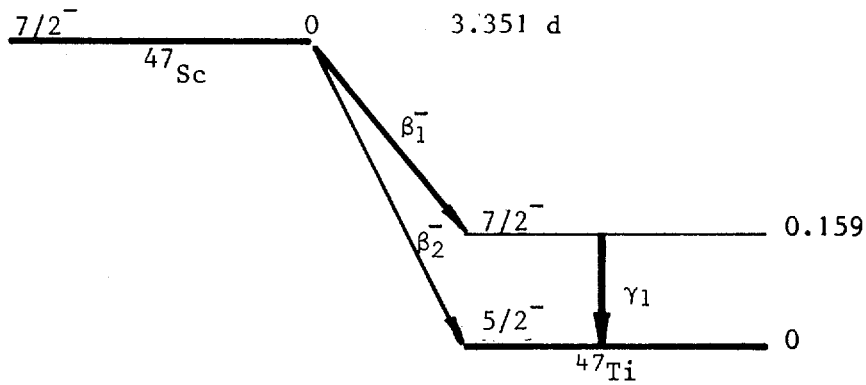


CTR

^{47}Ti (n,p) ^{47}Sc

Material constants see the reaction Ti (n,x)^{46}Sc

Disintegration scheme



Disintegration data |MED78|

+ ^{47}Sc: half-life = 3.351(2) d *

+ λ = $2.3941\times10^{-6}s^{-1}$

+ $E(\beta_1^-)$ max 440.6(20) keV

av 142.5(8) keV (68.0(20)%)

$E(\beta_2^-)$ max 600.0(20) keV

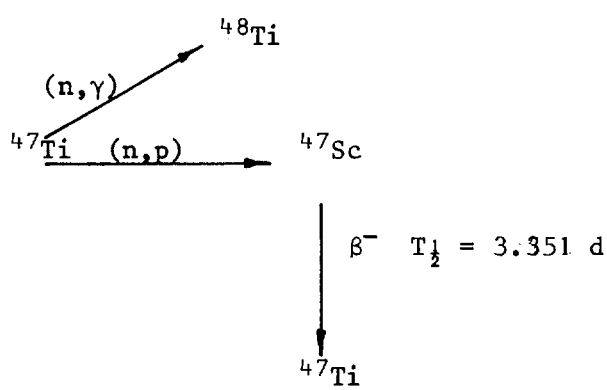
av 203.8(8) keV (32.0(20)%)

Total β^- av 162.1(9) keV (100(3)%)

+ $E(\gamma_1)$ 159.381(15) keV (68.0(20)%)

* See remarks at the reaction ^{45}Sc (n,γ)^{46}Sc.

Reaction of interest



Activities induced in titanium

See the reaction Ti(n,x)^{46}Sc.

Evaluated cross section data

620 group data : |Ph77|, | Zij77|

Integral data : $^{47}Ti(n,p)^{47}Sc$; $\langle\sigma\rangle^f = 2.174\ fm^2$ } |Zij76| ,|Zij77|

$^{48}Ti(n,np)^{47}Sc$; $\langle\sigma\rangle^f = 1.820\times10^{-4}\ fm^2$

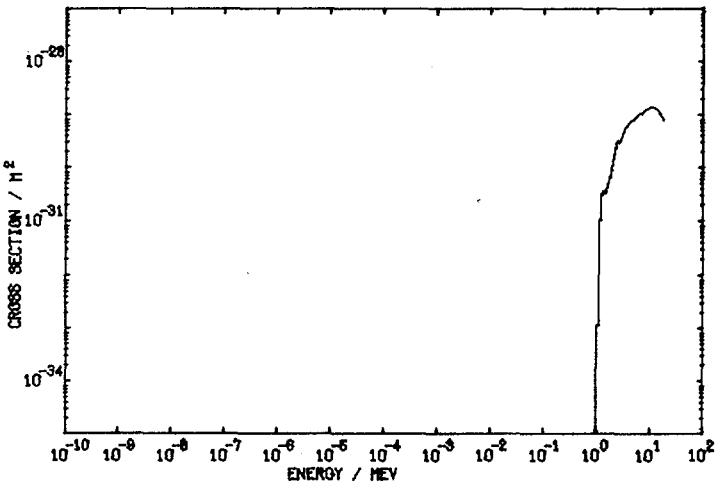
Response data

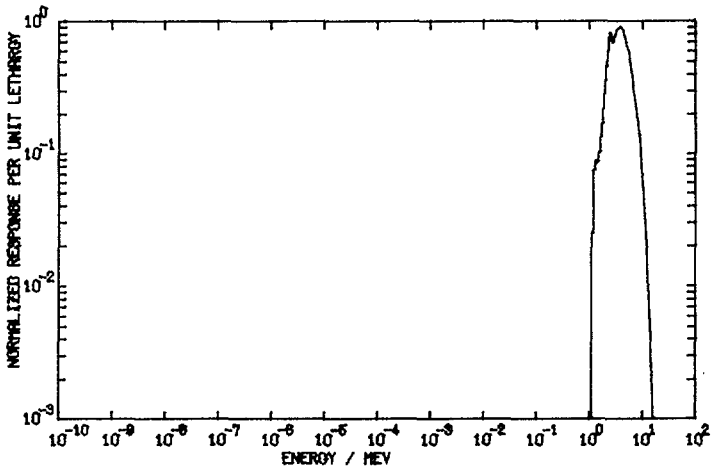
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: TI47(N,P)SC47

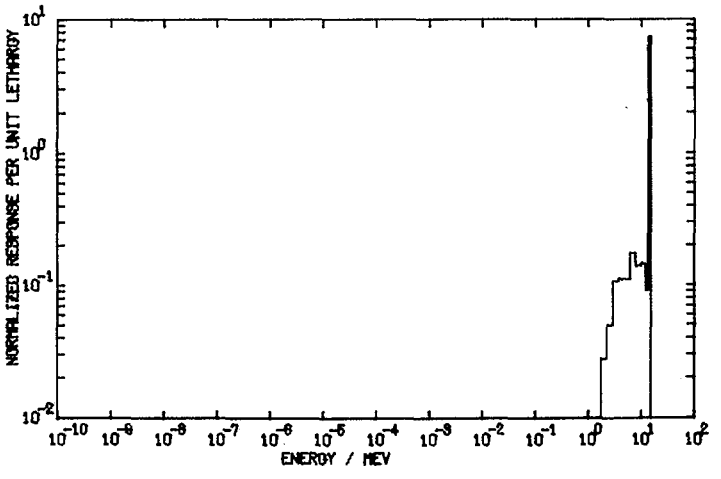
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	3.7E+00	1.4E+01	1.0E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.9E+00	8.0E+00	2.7E+00	5.7E+00	3.3E+00	4.6E+00	3.9E+00
235U	1.9E+00	7.5E+00	2.6E+00	5.4E+00	3.2E+00	4.4E+00	3.8E+00
CFRMF	1.7E+00	7.7E+00	2.4E+00	5.4E+00	3.0E+00	4.3E+00	3.6E+00
SIG.SIG.	1.7E+00	7.4E+00	2.4E+00	5.2E+00	2.9E+00	4.1E+00	3.5E+00
MTR	1.8E+00	7.6E+00	2.4E+00	5.2E+00	3.0E+00	4.2E+00	3.6E+00

ALL ENERGY VALUES IN MEV.





MTR

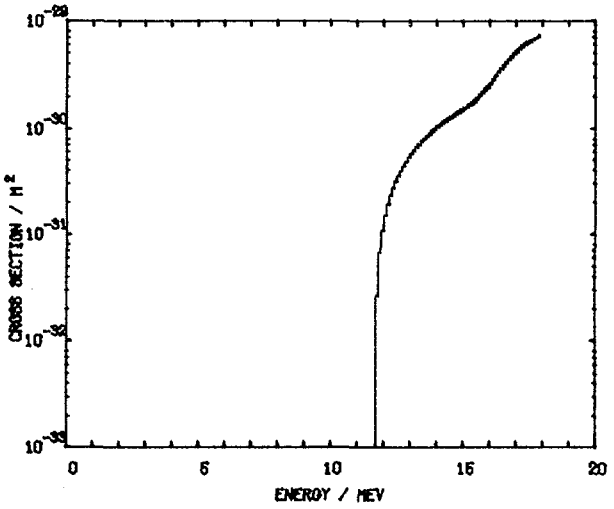


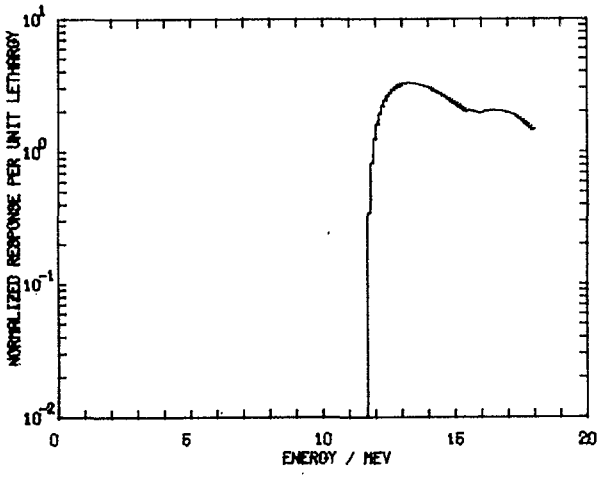
CTR

RESPONSE DATA FOR THE REACTION: TI48(N,NP)SC47

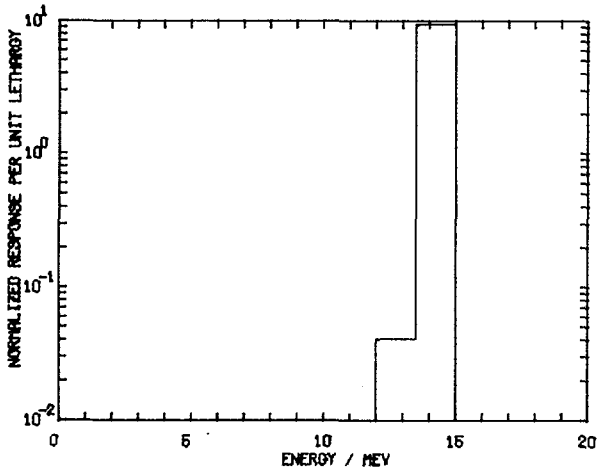
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.2E+01	1.8E+01	1.3E+01	1.6E+01	1.4E+01	1.5E+01	1.4E+01
235U	1.2E+01	1.7E+01	1.3E+01	1.6E+01	1.3E+01	1.5E+01	1.4E+01
CFRMF	1.2E+01	1.8E+01	1.3E+01	1.6E+01	1.4E+01	1.5E+01	1.4E+01
SIG.SIG.	1.2E+01	1.7E+01	1.3E+01	1.6E+01	1.4E+01	1.5E+01	1.4E+01
MTR	1.2E+01	1.7E+01	1.3E+01	1.6E+01	1.4E+01	1.5E+01	1.4E+01

ALL ENERGY VALUES IN MEV.





MTR

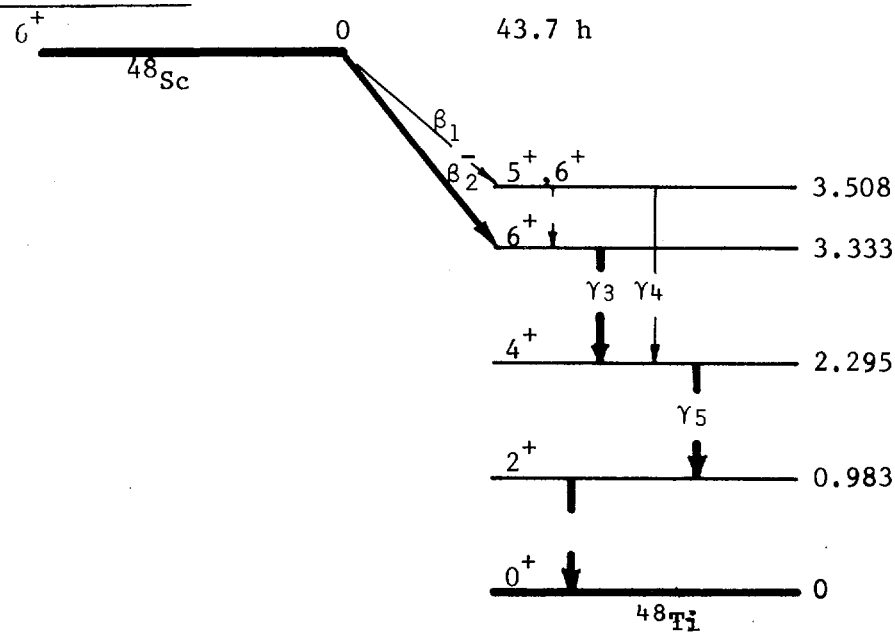


CTR

^{48}Ti (n,p) ^{48}Sc

Material constants. See the reaction Ti (n,x)^{46}Sc.

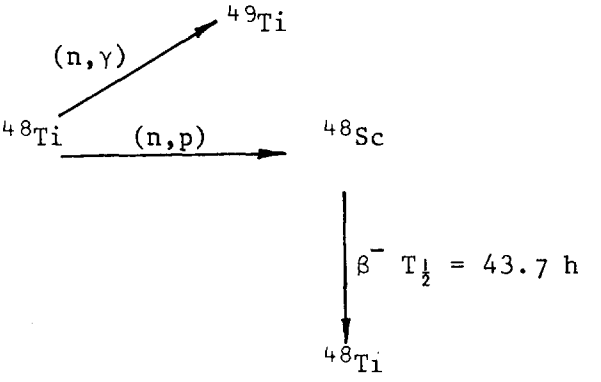
Disintegration scheme



Disintegration data |MED78|

+	^{48}Sc: half-life = 43.7(1) h			
+	λ = 4.4060×10^{-6} s^{-1}			
+	$E(\beta_1^-)$	max	482(6) keV	
+		av	157.9 (23) keV	9.85(9)%
+	$E(\beta_2^-)$	max	657(6) keV	
+		av	226.5(25) keV	90.0(3)%
+	$E(\beta_3^-)$	max	1694(6)keV	
+		av	680(3) keV	0.6 %
+	$E(\beta_4^-)$	max	3006(6)keV	
+		av	1299(3)keV	0.6 %
+	$E(\beta^-)$	av	229(3)keV	101.0(4)%
+	$E(\gamma_1)$		175.357(5) keV	7.47(8)%
+	$E(\gamma_2)$		983.5010(20) keV	100.0(5)%
+	$E(\gamma_3)$		1037.5 keV	97.5(5)%
+	$E(\gamma_4)$		1212.849(7) keV	2.380(22)%
+	$E(\gamma_5)$		1312.087(3) keV	100.0(5)%

Reaction of interest



Activities induced in titanium

See the reaction $Ti(n,x)^{46}Sc$.

Evaluated cross section data

620 group data : |Ph77|, | Zij77|

Integral data : $\langle\sigma\rangle^f$ = 0.01695 fm^2 |Zij76|,|Zij77|

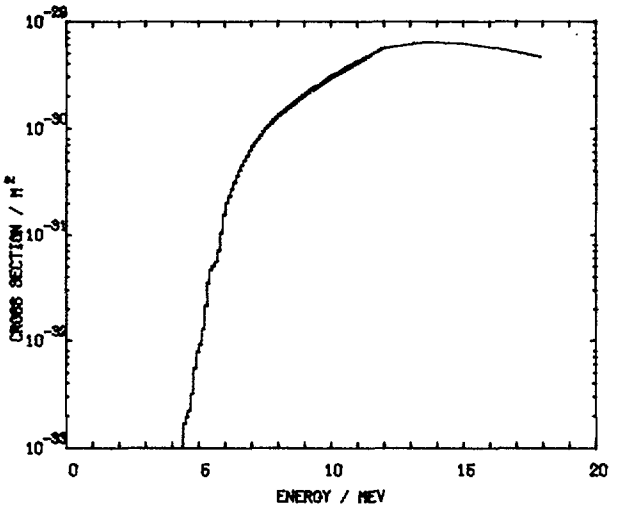
Response data

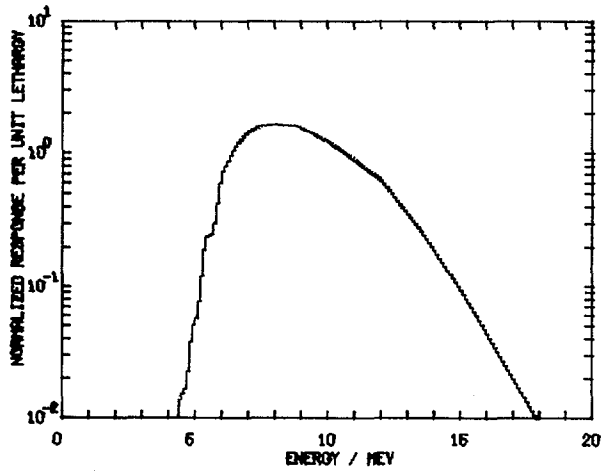
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: TI48(N,P)SC48

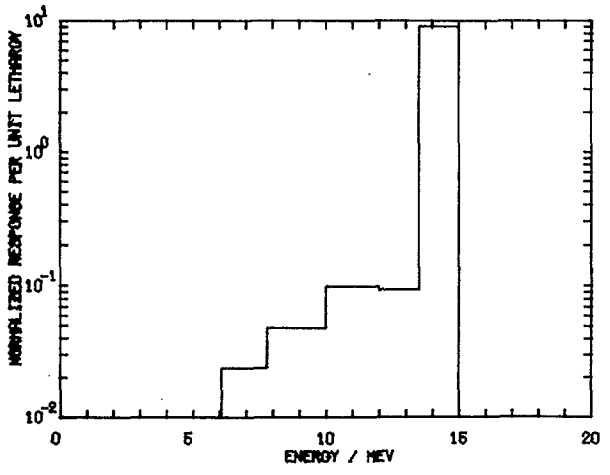
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	6.0E+00	1.3E+01	6.9E+00	1.1E+01	7.6E+00	9.3E+00	8.4E+00
235U	5.9E+00	1.2E+01	6.7E+00	1.0E+01	7.4E+00	8.8E+00	8.0E+00
CFRMF	6.0E+00	1.3E+01	6.9E+00	1.0E+01	7.6E+00	9.1E+00	8.3E+00
SIG.SIG.	5.9E+00	1.2E+01	6.8E+00	1.0E+01	7.4E+00	8.9E+00	8.1E+00
MTR	6.0E+00	1.3E+01	6.9E+00	1.0E+01	7.6E+00	9.2E+00	8.4E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

^{55}Mn (n,2n) ^{54}Mn

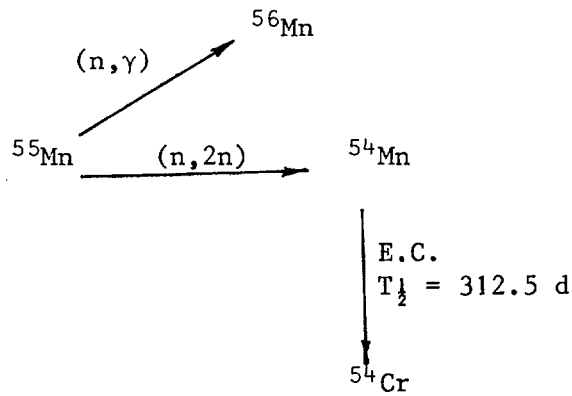
Material constants

See the reaction $^{55}Mn(n,\gamma)^{56}Mn$

Disintegration scheme and data

See the reaction $^{54}Fe(n,p)^{54}Mn$.

Reaction of interest



Activities induced in manganese

See the reaction $^{55}Mn(n,\gamma)^{56}Mn$.

Evaluated cross section data

620 group data : |Ma75|, | Zij77 |

Integral data : $\langle\sigma\rangle^f = 0.0232$ fm^2 | Zij77 |

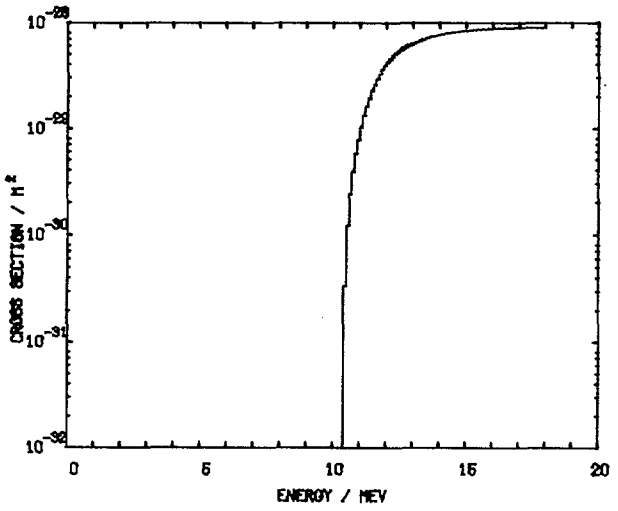
Response data

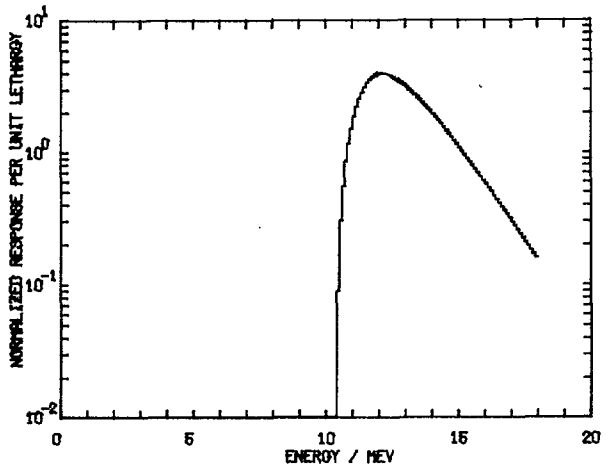
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: MN55(N,2N)MN54

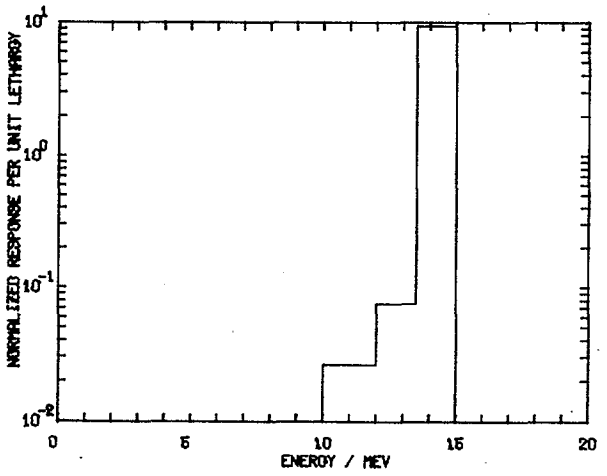
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01
235U	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01
CFRMF	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01
SIG.SIG.	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01
MTR	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01

ALL ENERGY VALUES IN MEV.





MTR



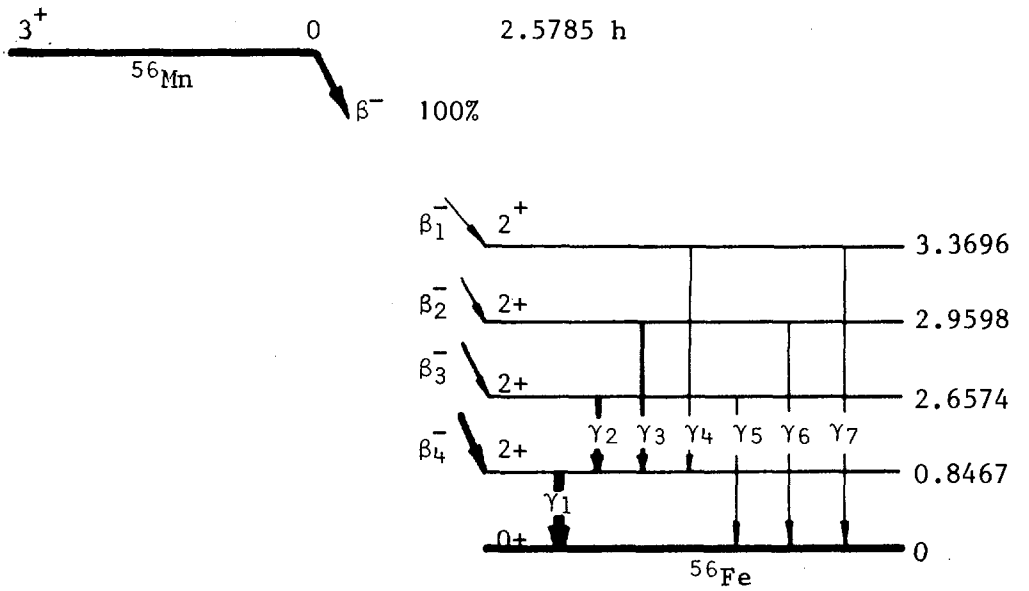
CTR

^{55}Mn (n,γ) ^{56}Mn

Material constants

Relative atomic mass of element	: A_r(Mn)	= 54.9380(1)	|Ho79|,
Mass density	: ρ	= 7.20 $Mg.m^{-3}$	|We79|
Melting point	: T	= 1517.15 K = 1244(3) °C	
Number of atoms per unit mass	: N_m	= $10.96\times10^{24} kg^{-1}$	
Number of atoms per unit volume	: N_v	= $78.93\times10^{27} m^{-3}$.	
Isotopic mole fraction	: x(^{55}Mn)	= 100%	|Ho79|

Disintegration scheme



Disintegration data |MED78|

^{56}Mn: half-life = 2.5785(6) h

λ = $74.672\times10^{-6} s^{-1}$

+	$E(\beta_1^-)$	max	324.8(12) keV	
+		av	98.8(5) keV	(1.16(3)%)
+	$E(\beta_2^-)$	max	734.6(12) keV	
+		av	254.8(5) keV	(14.6(4)%)
+	$E(\beta_3^-)$	max	1037.0(12) keV	
+		av	381.5(6) keV	(27.8(8)%)
+	$E(\beta_4^-)$	max	2847.7(12) keV	
+		av	1216.3(6) keV	(56.3(9)%)
+	Total β^-	av	829.8(9) keV	(100.0(13)%)

3 weak β's omitted (ΣPβ = 0.12%)

^{56}Mn: $E(\gamma_1)$ 846.754(20) keV (98.9(3)%)

$E(\gamma_2)$ 1810.72(4) keV (27.2(8)%)

$E(\gamma_3)$ 2113.05(4) keV (14.3(4)%)

$E(\gamma_4)$ 2522.88(6) keV (0.99(3)%)

$E(\gamma_5)$ 2657.45(5) keV (0.653(20)%)

$E(\gamma_6)$ 2959.77(6) keV (0.306(10)%)

$E(\gamma_7)$ 3369.60(7) keV (0.168(10)%)

3 weak γ's omitted (ΣP_γ = 0.16%)

Activities induced in manganese

^{55}Mn(n,γ)^{56}Mn

$T_{\frac{1}{2}}$ = 2.5785 h |MED78| σ_{act} = 1323(20) fm^2 |Ry76|

I = 1400(40) fm^2|Mu73| I' = 780(30) fm^2 |Ry76|

g value Westcott convention 1

s_o value Westcott convention 0.6653

^{55}Mn(n,2n)^{54}Mn

$T_{\frac{1}{2}}$ = 312.5 d |MED78| $\langle\sigma\rangle$ = 0.0244(15) fm^2 |Fa76|, |Fa78|

Evaluated cross section data

620 group data : |Ei74|, |Zij77|

Integral data : $g.\sigma_o$ = 1337 fm^2 |Zij77|

I = 1560 fm^2

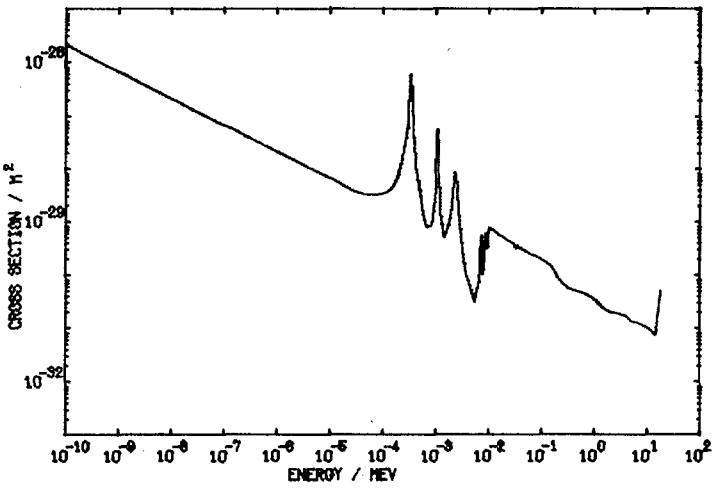
Response data

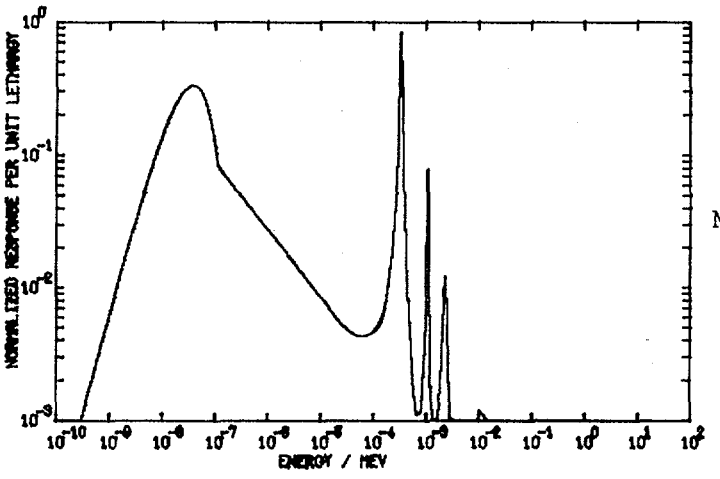
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: MN55(N,G)MN56

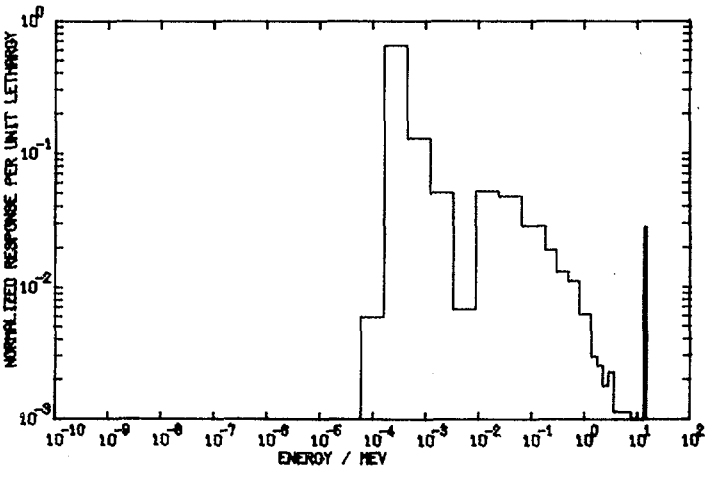
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.7E-04	6.8E-02	1.7E-04	1.2E-03	1.7E-04	1.7E-04	1.7E-04
252CF	4.0E-02	4.0E+00	1.9E-01	2.0E+00	4.5E-01	1.2E+00	8.0E-01
235U	3.4E-02	3.7E+00	1.7E-01	1.9E+00	4.0E-01	1.1E+00	7.2E-01
CFRMF	2.8E-04	2.8E-01	3.2E-04	1.5E-02	3.2E-04	1.0E-03	3.4E-04
SIG.SIG.	2.8E-04	4.0E-01	3.2E-04	4.0E-02	3.2E-04	1.1E-03	3.4E-04
MTR	5.5E-09	3.4E-04	1.6E-08	8.0E-07	2.8E-08	8.0E-08	4.5E-08

ALL ENERGY VALUES IN MEV.





MTR



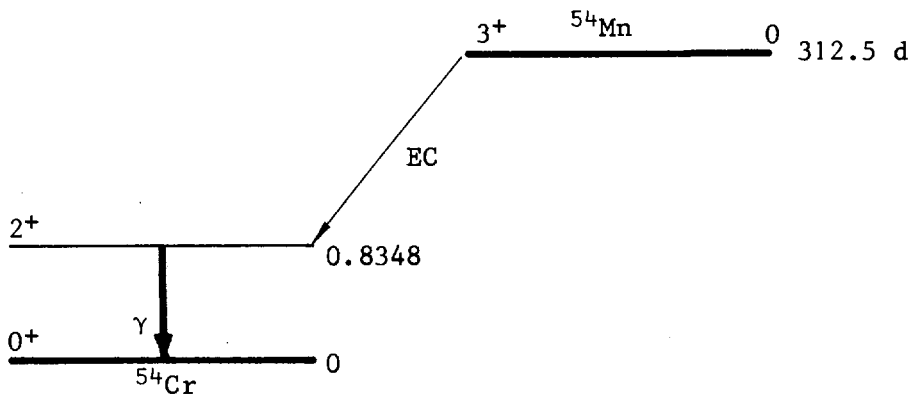
CTR

$^{54}Fe(n,p)^{54}Mn$

Material constants

See the reaction $^{58}Fe(n,\gamma)^{59}Fe$.

Disintegration scheme



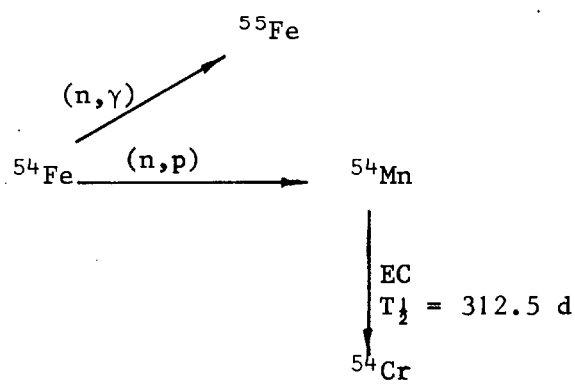
Disintegration data |MED78|

^{54}Mn: half-life = 312.5(5) d

λ = $25.672\times10^{-9}\ s^{-1}$

\+ E(γ) 834.827(21) keV (99.9760(20)%)

Reaction of interest



Activities induced in iron

$^{54}Fe(n,p)^{54}Mn$	$T_{\frac{1}{2}}$ = 312.5 d |MED78|	$\langle\sigma\rangle$ = 7.97(49) fm^2	|Fa76|
$^{54}Fe(n,\gamma)^{55}Fe$	$T_{\frac{1}{2}}$ = 2.7 a |Se74|	$\langle\sigma\rangle$ = 225(18) fm^2	|Mu73|
$^{56}Fe(n,p)^{56}Mn$	$T_{\frac{1}{2}}$ = 2.5785 h |MED78|	$\langle\sigma\rangle$ = 0.1035(75) fm^2	|Fa76|
+ $^{58}Fe(n,\gamma)^{59}Fe$	$T_{\frac{1}{2}}$ = 44.529 d |MED78|	σ_{act} = 115(2) fm^2	|Mu73|
	I = 119(7) fm^2 |Mu73|		

Evaluated cross section data

620 group data : |Ma75|, |Zij77 |

Integral data : $\langle\sigma\rangle^f = 7.846\ fm^2$ | Zij77|

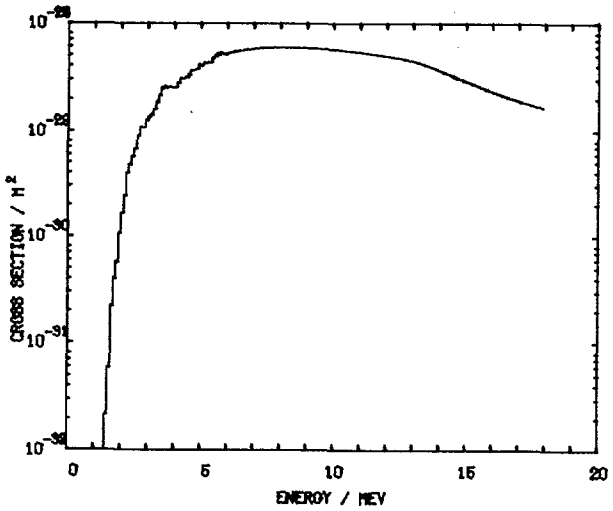
Response data

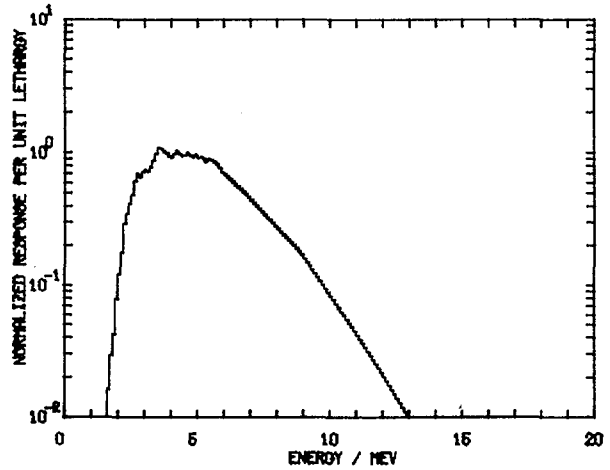
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: FE54(N,P)MN54

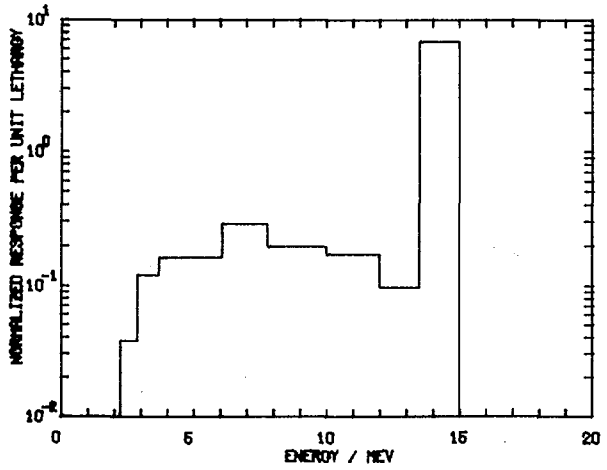
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	3.7E+00	1.4E+01	7.8E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	2.5E+00	8.2E+00	3.2E+00	6.1E+00	3.8E+00	5.2E+00	4.5E+00
235U	2.4E+00	7.8E+00	3.2E+00	5.9E+00	3.7E+00	5.0E+00	4.3E+00
CFRMF	2.4E+00	8.0E+00	3.1E+00	6.0E+00	3.6E+00	5.0E+00	4.3E+00
SIG.SIG.	2.3E+00	7.7E+00	3.0E+00	5.9E+00	3.5E+00	4.9E+00	4.0E+00
MTR	2.3E+00	7.9E+00	3.0E+00	5.8E+00	3.6E+00	4.9E+00	4.2E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

^{56}Fe (n,p) ^{56}Mn

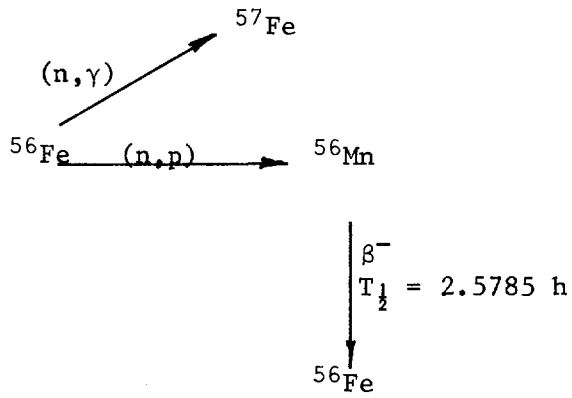
Material constants

See the reaction $^{58}Fe(n,\gamma)^{59}Fe$

Disintegration scheme and data

See the reaction $^{55}Mn(n,\gamma)^{56}Mn$

Reaction of interest



Activities induced in iron

See the reaction $^{54}Fe(n,p)^{54}Mn$

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : $\langle\sigma\rangle$ = 0.1035 fm^2 |Zij76|, |Zij77|

Remark

The reaction ^{56}Fe (n,γ) leads to the stable product ^{57}Fe.
For the absorption cross section of ^{56}Fe, sometimes required for a burn-up correction, the following value is available :

$$\sigma_a = 263\ (21)\ \text{fm}^2\ |\text{Mu73}|$$

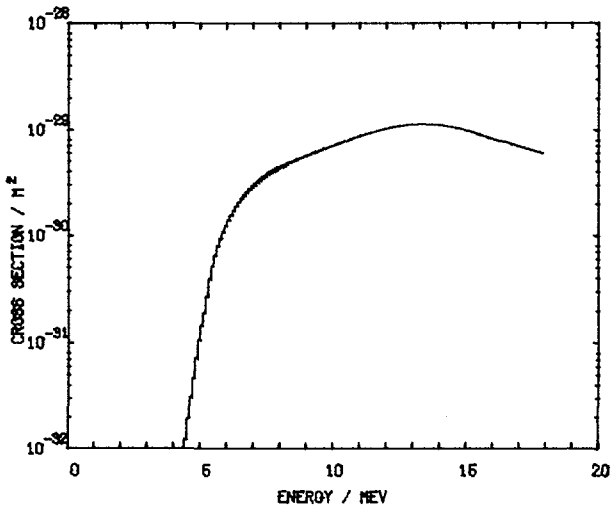
Response data

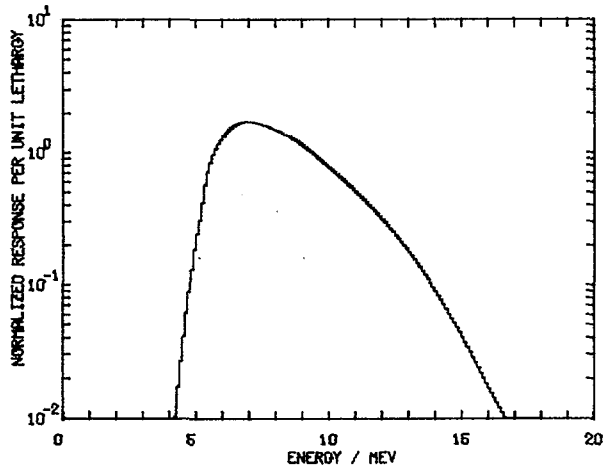
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: FE56(N,P)MN56'

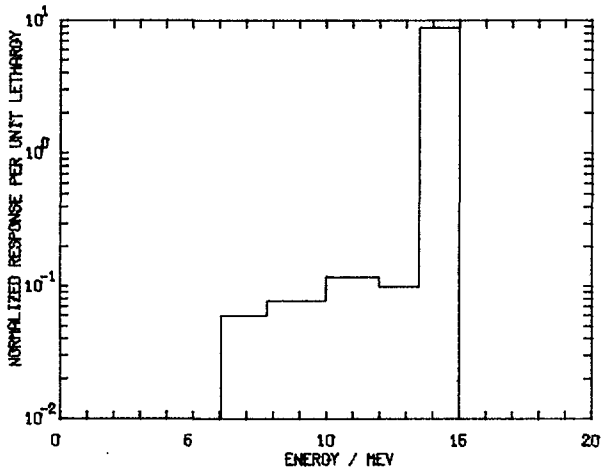
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.0E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	5.5E+00	1.2E+01	6.2E+00	9.3E+00	6.8E+00	8.2E+00	7.5E+00
235U	5.4E+00	1.1E+01	6.1E+00	8.9E+00	6.6E+00	7.9E+00	7.2E+00
CFRMF	5.4E+00	1.2E+01	6.2E+00	9.2E+00	6.8E+00	8.1E+00	7.4E+00
SIG.SIG.	5.5E+00	1.1E+01	6.1E+00	8.9E+00	6.7E+00	7.9E+00	7.2E+00
MTR	5.4E+00	1.2E+01	6.2E+00	9.2E+00	6.8E+00	8.2E+00	7.4E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

^{58}Fe (n,γ) ^{59}Fe

Material constants

Relative atomic mass of element: $A_r(Fe)$ = 55.847(3) |Ho79|

Mass density : ρ = 7.874 $Mg.m^{-3}$ |We79|

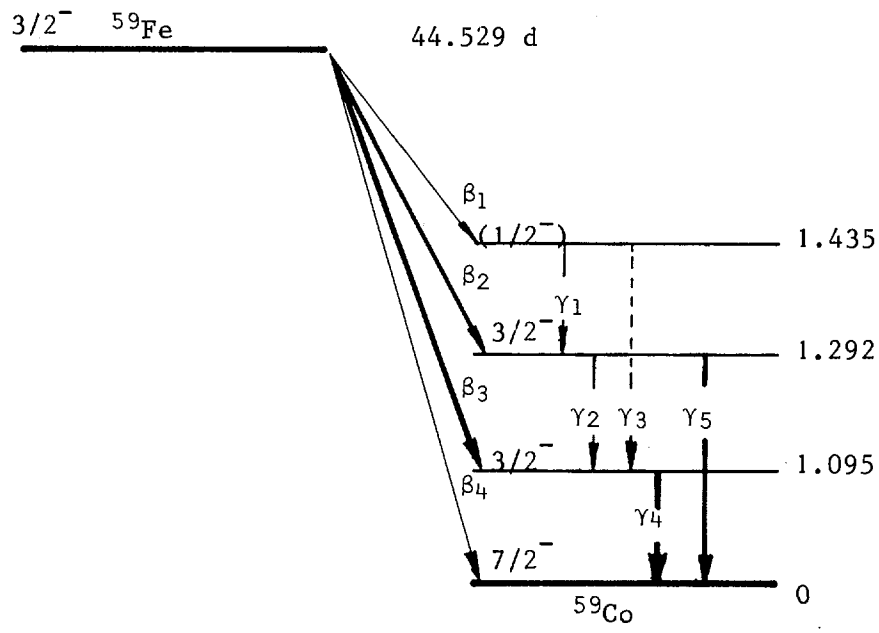
Melting point : T = 1808.15 K = 1535 °C |We79|

\+ Number of atoms per unit mass : N_m = $10.78\times10^{24} kg^{-1}$

Number of atoms per unit volume: N_v = $84.91\times10^{27} m^{-3}$

Isotopic mole fractions : $x(^{54}Fe)$= 5.8(1) %
\+ $x(^{56}Fe)$=91.8(1) %
\+ $x(^{57}Fe)$= 2.1(1) %
\+ $x(^{58}Fe)$= 0.3(1) %
|Ho79|

Disintegration scheme



Disintegration data |MED78|

\+ ^{59}Fe: half-life = 44.529(7) d

\+ λ = $0.18016\times10^{-6} s^{-1}$

\+ $E(\beta_1^-)$ max 130.8(20) keV
av 35.8(6) keV (1.27(3)%)

\+ $E(\beta_2^-)$ max 273.4(20) keV
av 80.8(6) keV (45.6(8)%)

\+ $E(\beta_3^-)$ max 465.8(20) keV
av 149.3(7) keV (52.8(12)%)

$E(\beta_4^-)$ max 1565.0(20) keV
av 635.8(8) keV (0.18(4)%)

Total β^- av 117.4(8) keV (99.9(15)%)
1 weak β omitted ($\Sigma P\beta$ = 0.08%)

$E(\gamma_1)$ 142.648(4) keV (1.00(3)%)
$E(\gamma_2)$ 192.344(6) keV (3.00(7)%)
$E(\gamma_3)$ 334.80(20) keV (0.270(10)%)
$E(\gamma_4)$ 1099.224(25) keV (56.1(12)%)
$E(\gamma_5)$ 1291.56(3) keV (43.6(8)%)

2 weak γ's omitted ($\Sigma P\gamma$ = 0.08%)

Activities induced in iron

See reaction $^{54}Fe\ (n,\gamma)\ ^{54}Mn$.

Evaluated cross section data

620 group data : |Ma75|, |Zij77|
Integral data : $g.\sigma_0$ = 118.7 fm^2 |Zij77|
I = 155.8 fm^2

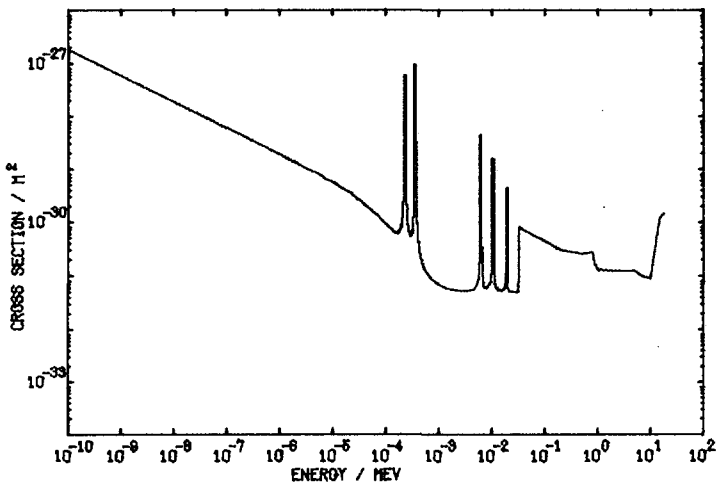
Response data

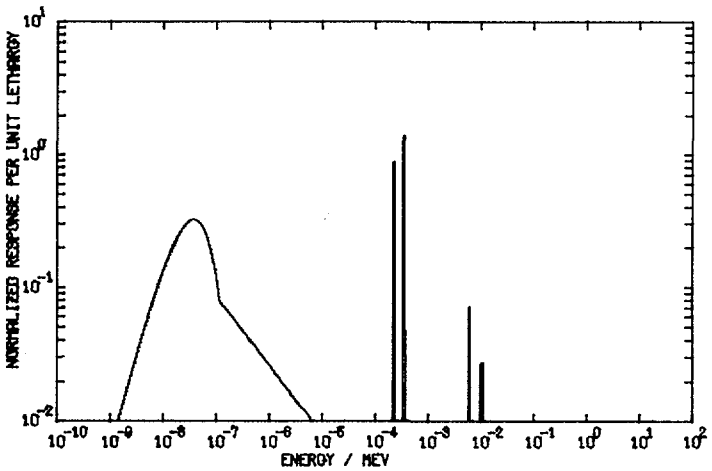
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: FE58(N,G)FE59

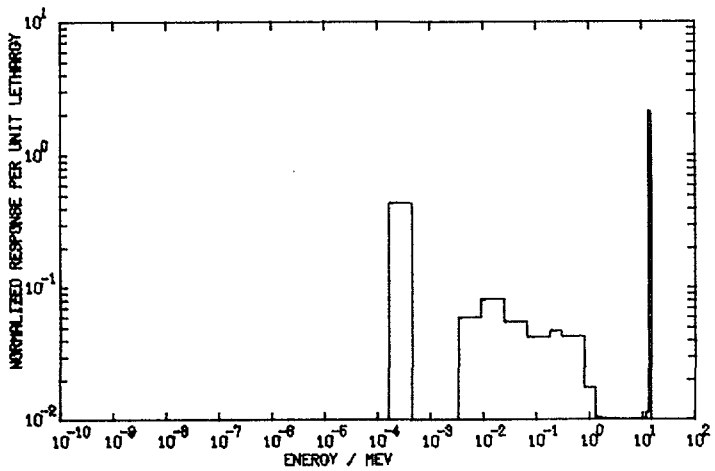
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.7E-04	1.4E+01	1.7E-04	1.4E+01	1.7E-04	6.8E-02	3.4E-03
252CF	1.2E-01	4.9E+00	4.0E-01	2.7E+00	6.9E-01	1.7E+00	1.0E+00
235U	9.6E-02	4.5E+00	3.6E-01	2.5E+00	6.3E-01	1.6E+00	9.6E-01
CFRMF	2.2E-04	8.4E-01	3.4E-04	2.6E-01	3.4E-04	6.3E-02	6.0E-03
SIG.SIG.	2.2E-04	1.0E+00	3.4E-04	3.4E-01	3.4E-04	1.2E-01	1.1E-02
MTR	5.8E-09	3.4E-04	1.7E-08	2.3E-06	3.0E-08	8.8E-08	4.8E-08

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{59}Co\ (n,\alpha)\ ^{56}Mn$

Material constants
Activities induced in cobalt } see reaction $^{59}Co\ (n,\gamma)^{60}Co$

Disintegration scheme
Disintegration data } see reaction $^{56}Fe\ (n,p)^{56}Mn$

Evaluated cross section data

620 group data |Ma75|, |Zij77|

Integral data : for a ^{235}U fission spectrum

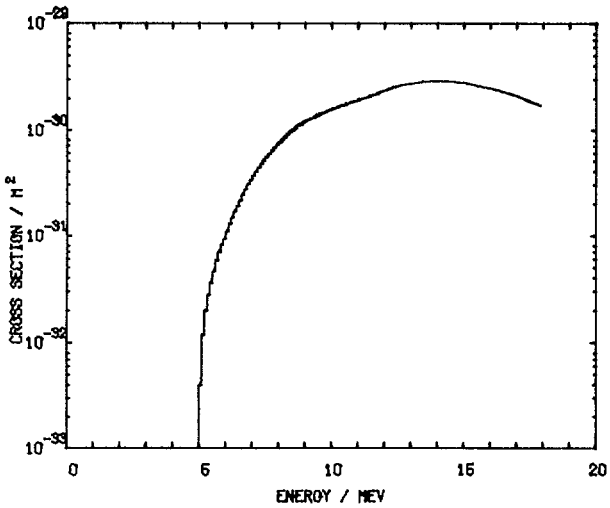
$\langle\sigma\rangle_m = 0.143\ (10)\ mb = 0.0143\ fm^2$ |Fa78|

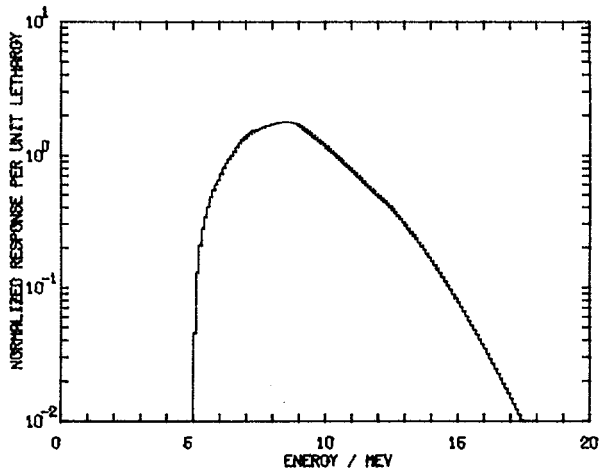
$\langle\sigma\rangle_c = 0.1457\ mb = 0.01457\ fm^2$ |Zij77|

RESPONSE DATA FOR THE REACTION: C059(N,A)MN56

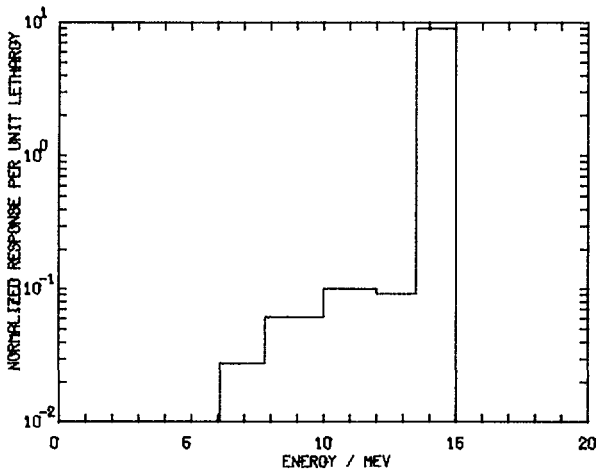
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.2E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	5.9E+00	1.3E+01	6.9E+00	1.0E+01	7.6E+00	9.1E+00	8.3E+00
235U	5.7E+00	1.2E+01	6.7E+00	9.7E+00	7.3E+00	8.7E+00	8.0E+00
CFRMF	5.8E+00	1.2E+01	6.8E+00	1.0E+01	7.5E+00	8.9E+00	8.2E+00
SIG.SIG.	5.8E+00	1.2E+01	6.7E+00	9.7E+00	7.3E+00	8.7E+00	8.0E+00
MTR	5.8E+00	1.2E+01	6.8E+00	1.0E+01	7.6E+00	9.0E+00	8.3E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

^{59}Co (n,2n) ^{58}Co

Material constants
Activities induced in cobalt } see the reaction $^{59}Co(n,\gamma)^{60}Co$

Disintegration scheme
Disintegration data } see the reaction $^{58}Ni(n,p)^{58}Co$

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : for a ^{235}U fission spectrum :

$\langle\sigma\rangle_c$= 0.262 mb = 0.0262 fm^2 |Ma 75,2|

(for a Watt representation) $\langle\sigma\rangle_c$ = 0.1624 mb = 0.01624 fm^2 |Zij77|

for a ^{252}Cf spectrum $\langle\sigma\rangle_m$= 0.57(6) mb= 0.057 fm^2 |Fa78|

Remark

Because of the high threshold value (about 10.6 MeV) and the uncertainty in the shape of the ^{235}U fission neutron spectrum above about 8 MeV, the calculated cross section value, averaged over a fission neutron spectrum is strongly dependent on the representation of the fission neutron spectrum.

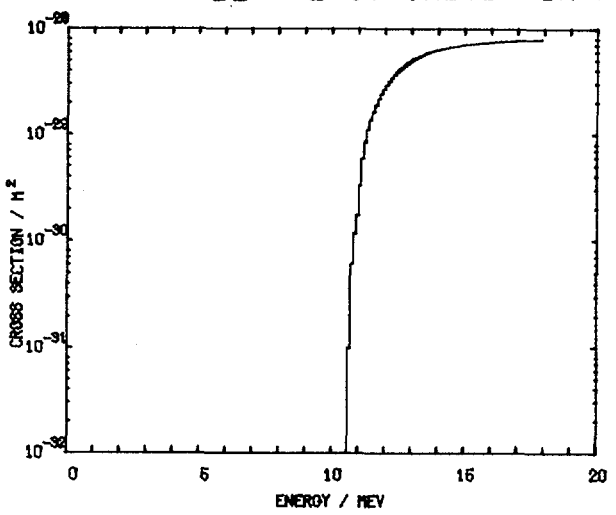
Response data

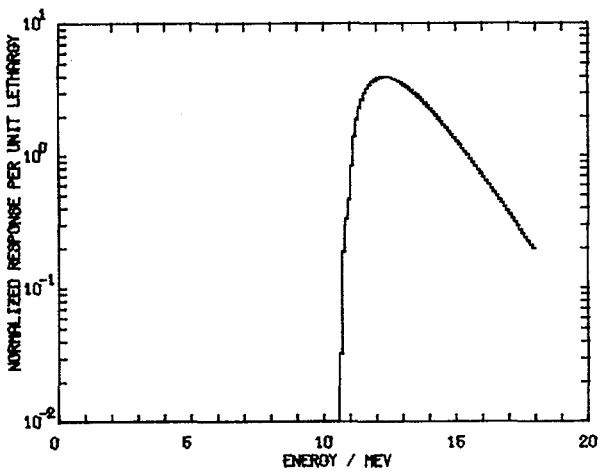
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: C059(N,2N)C058

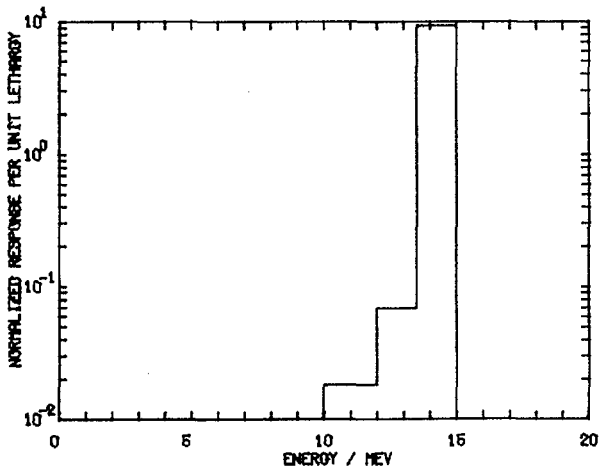
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.4E+01	1.3E+01
235U	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01
CFRMF	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.4E+01	1.3E+01
SIG.SIG.	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01
MTR	1.1E+01	1.6E+01	1.2E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{59}Co\ (n,\gamma)\ ^{60}Co$

Material constants

Relative atomic mass of element: $A_r(Co) = 58.9332(1)$ |Ho79|

Mass density : $\rho = 8.9\ Mg.m^{-3}$ |We79|

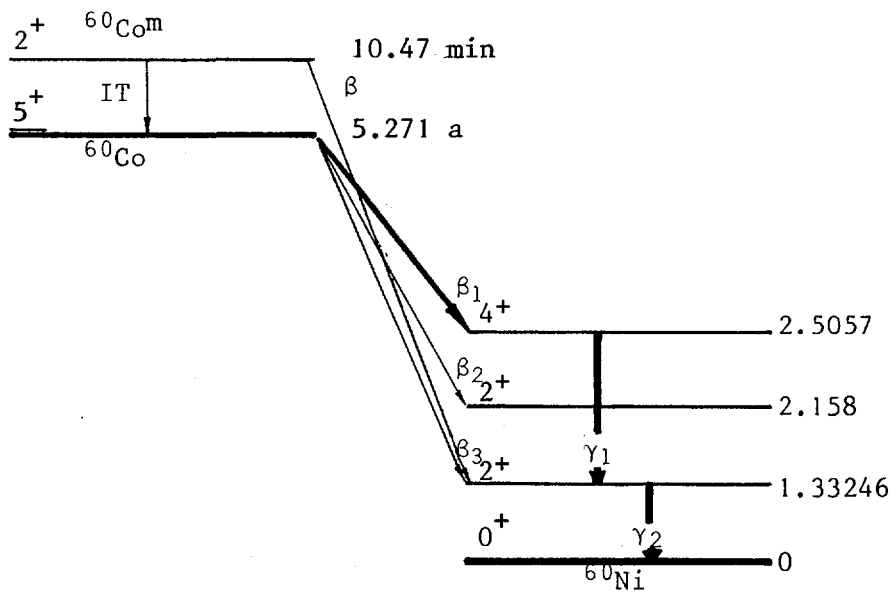
Melting point : $T = 1768.15\ K = 1495^{o}C$ |We79|

Number of atoms per unit mass : $N_m = 10.22\times10^{24} kg^{-1}$

Number of atoms per unit volume: $N_v = 90.95\times10^{27} m^{-3}$

Isotopic mole fraction : $x(^{59}Co) = 100\%$ |Ho79|

Disintegration scheme



Disintegration data |MED78|

+ $^{60}Co^{m}$: half-life = 10.47(2) min

$\lambda = 1.1034\times10^{-3} s^{-1}$

+ IT $E(\gamma) = 58.6$ keV (2.07(13)%)

+ $E(\beta^-)$ max = 1549.73(14)

+ av = 606.38(6) (0.24%)

+ $E(\gamma)$ av = 1330(10) (0.25%)

+ ^{60}Co : half-life = 5.271(1) a *)

+ $\lambda = 4.1671\times10^{-9} s^{-1}$

+ $E(\beta_1^-)$ max 317.87(1) keV

av 95.80(10) keV (99.920(20)%)

Total β^- av 96.22(10) keV (100.000(20)%)

2 weak β's omitted ($\Sigma P\beta = 0.09\%$)

*) 1a = 365.24220 d = 31556926 s |ISO75|

+ $E(\gamma_1)$ = 1173.210(10) keV (99.900 (20)%)

+ $E(\gamma_2)$ = 1332.470(10) keV (99.9824(5)%)

+ 4 weak γ's omitted (ΣP_γ = 0.02%)

Activities induced in cobalt

$^{59}Co(n,\gamma)^{60}Co^m$

$T_{\frac{1}{2}}$ = 10.47 min |MED78| σ_{act} = 2000(200) fm^2

$^{59}Co(n,\gamma)^{60}Co$

+ $T_{\frac{1}{2}}$ = 5.271 a |MED78| σ_{act} = 1700(200) fm^2 (direct) |Mu73|

σ_{act} = 3720(20) fm^2 (direct+indirect)

I = 7550(150) fm^2 |Mu73| I' = 5310 fm^2 |Zij65,2|

g value Westcott convention 1.00

s_0 value Westcott convention 1.611

$^{60}Co^m(n,\gamma)^{61}Co$ $T_{\frac{1}{2}}$ = 1.6 h |Se74| σ_{act} = 5800(800) fm^2

$^{60}Co(n,\gamma)^{61}Co$ $T_{\frac{1}{2}}$ = 1.6 h |Se74| σ_{act} = 200(20) fm^2 |Mu73|

+ $^{59}Co(n,p)^{59}Fe$ $T_{\frac{1}{2}}$ = 44.529d |MED78| $\langle\sigma\rangle$ = 0.142(14) fm^2 |Ca74|

$^{59}Co(n,\alpha)^{56}Mn$ $T_{\frac{1}{2}}$ = 2.785 h |Ma76| $\langle\sigma\rangle$ = 0.0143(10) fm^2 |Fa76|, |Fa78|

$^{59}Co(n,2n)^{58}Co$ $T_{\frac{1}{2}}$ = 70.80(8) d |MED78| $\langle\sigma\rangle$=0,40(4)mb=0.040fm^2 |Ca74|

Evaluated cross section data

620 group data : |Ma75|, | Zij77 |

+ Integral data : $g.\sigma_0$ = 3739 fm^2 | Zij77 |

I = 7576 fm^2

Remarks:

With the gamma ray spectrum of ^{60}Co there occur escape peaks at energies of 822 keV and 662 keV.

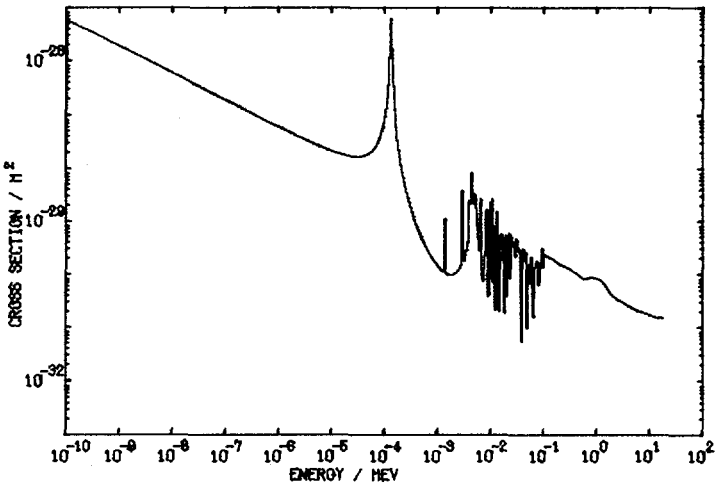
Response data

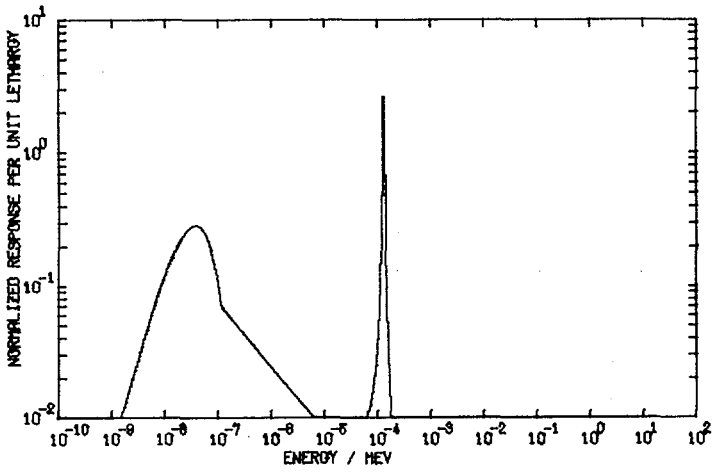
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: C059(N,G)C060

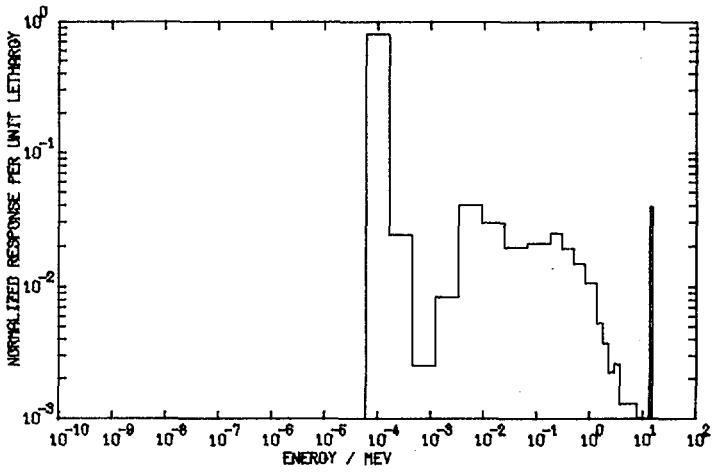
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	6.1E-05	6.8E-02	6.1E-05	6.1E-05	6.1E-05	6.1E-05	6.1E-05
252CF	1.1E-01	3.8E+00	3.4E-01	1.9E+00	6.3E-01	1.3E+00	9.6E-01
235U	9.2E-02	3.6E+00	3.0E-01	1.8E+00	5.8E-01	1.2E+00	8.8E-01
CFRMF	1.2E-04	3.2E-01	1.3E-04	1.6E-04	1.3E-04	1.4E-04	1.3E-04
SIG.SIG.	1.0E-04	6.6E-01	1.3E-04	1.1E-01	1.3E-04	2.2E-04	1.3E-04
MTR	6.0E-09	1.4E-04	1.9E-08	1.3E-04	3.4E-08	2.4E-07	5.8E-08

ALL ENERGY VALUES IN MEV.





MTR



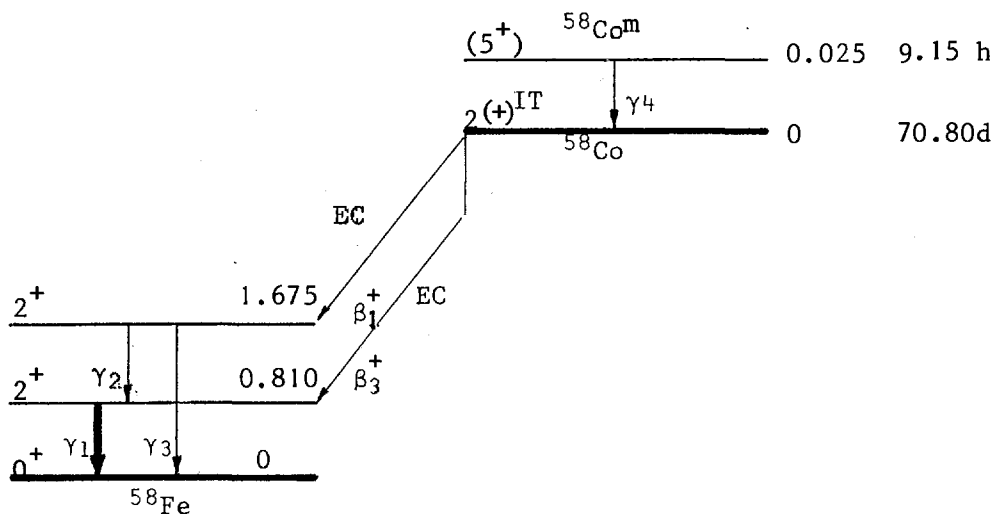
CTR

^{58}Ni (n,p) ^{58}Co

Material constants

+	Relative atomic mass of element	: A_r(Ni)	= 58.70(1)	|Ho79|
	Mass density	: ρ	= 8.902 $Mg.m^{-3}$	|We79|
	Melting point	: T	= 1179.85 K = 1453°C	|We79|
+	Number of atoms per unit mass	: N_m	= $10.37\times 10^{24} kg^{-1}$	
+	Number of atoms per unit volume	: N_v	= $92.32\times 10^{27} m^{-3}$	
+	Isotopic mole fractions	: $x(^{58}Ni)$	= 68.27(1) %	|Ho79|
+		$x(^{60}Ni)$	= 26.10(1) %	|Ho79|
+		$x(^{61}Ni)$	= 1.13(1) %	|Ho79|
+		$x(^{62}Ni)$	= 3.59(1) %	|Ho79|
+		$x(^{64}Ni)$	= 0.91(1) %	|Ho79|

Disintegration scheme

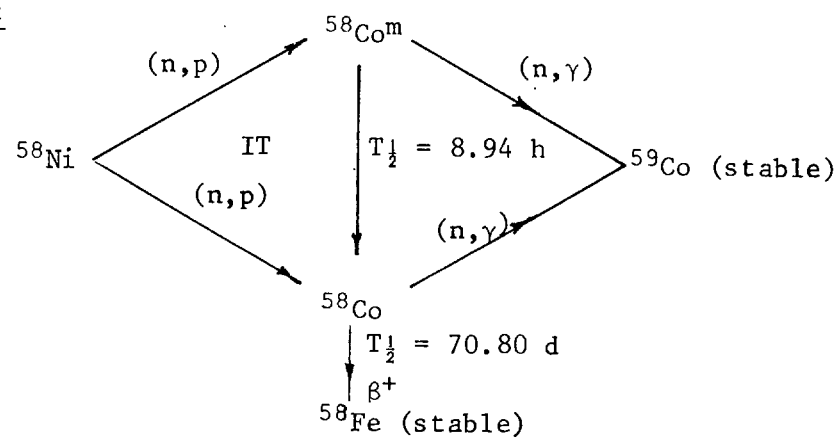


Disintegration data |MED78|

+	$^{58}Co^m$:	half-life	= 9.15(10) h
+		λ	= $21.043\times 10^{-6} s^{-1}$
+		$E(\gamma_4)$	= 24.88(6) keV ≈ 0.036% |Le78|
+	^{58}Co:	half-life	= 70.80(8) d
+		λ	= $0.11331\times 10^{-6} s^{-1}$
+		$E(\beta_1^+)$ max	474.6(14)keV
+		av	201.2(6) keV (15.00(5)%)

+	$E(\gamma_1)$	810.757(18) keV	(99.4 (3)%)
+	$E(\gamma_2)$	863.935(18) keV	(0.676(10)%)
+	$E(\gamma_3)$	1674.68(4) keV	(0.517(10)%)
	$E(\gamma^{\pm})$	511.0034(14) keV	(30.00 maximum)

Reaction of interest



Activities induced in nickel

+	$^{58}Ni(n,\gamma)^{59}Ni$	$T_{\frac{1}{2}}$ = 7.5(13)x10⁴ a |Ko77|	σ_0 = 460(30) fm²	> |Mu73|	
+	$^{62}Ni(n,\gamma)^{63}Ni$	$T_{\frac{1}{2}}$ = 96(4)a |Ko77|	σ_0 = 1420(30) fm²	> |Mu73|	
+	$^{64}Ni(n,\gamma)^{65}Ni$	$T_{\frac{1}{2}}$ = 2.520(2) h |Ko77|	σ_0 = 149(3) fm²	> |Mu73|	
+	$^{58}Ni(n,p)^{58}Co^m$	$T_{\frac{1}{2}}$ = 9.15(10) h |MED78|	$\langle\sigma\rangle$ = 3.40(22) fm²		See remarks
+	$^{58}Ni(n,p)^{58}Co$	$T_{\frac{1}{2}}$ = 70.80(8) d |MED78|	$\langle\sigma\rangle$ = 7.45 fm² (direct)		See remarks
			$\langle\sigma\rangle$ = 10.85(54) fm²	|Fa77|	(direct+ indirect)
+	$^{58}Ni(n,\alpha)^{55}Fe$	$T_{\frac{1}{2}}$ = 2.7 (1)a |Ko77|	$\langle\sigma\rangle$ = 0.30(9) fm²	|Ca74|	
+ +	$^{58}Ni(n,2n)^{57}Ni$	$T_{\frac{1}{2}}$ = 36.0 8(9)h |MED78|	$\langle\sigma\rangle$ = 0.00577(31)mb=0.000577fm	|Fa78|	
+	$^{58}Ni(n,np)^{57}Co$	$T_{\frac{1}{2}}$ = 271.5(5) d |PTB78|	$\langle\sigma\rangle$ = 0.022 fm²	|Zij65|	
+	$^{60}Ni(n,p)^{60}Co^m$	$T_{\frac{1}{2}}$ = 10.47(2) min |MED78|	$\langle\sigma\rangle$ = 0.21(3) fm²	|Ca74|	
+	$^{60}Ni(n,p)^{60}Co$	$T_{\frac{1}{2}}$ = 5.271 (1)a |MED78|	$\langle\sigma\rangle$ = 0.23(4) fm²	|Ca74|	
	$^{61}Ni(n,np)^{60}Co^m$	$T_{\frac{1}{2}}$ = 10.47(2) min |MED78|	$\langle\sigma\rangle$ < 0.5 fm²	|Zij65|	
+	$^{62}Ni(n,\alpha)^{59}Fe$	$T_{\frac{1}{2}}$ = 44.529(7)d |MED78|	$\langle\sigma\rangle$ = 0.009(7) fm²	|Ca74|	
	$^{58}Co^m(n,\gamma)^{59}Co$	stable	σ = 13.60(10) pm²	|Mu73|	
	$^{58}Co(n,\gamma)^{59}Co$	stable	σ = 0.1880(120) pm²	|Mu73|	

Evaluated cross section data

620 group data : |Ma75|, |Zij77|
Integral data : $\langle\sigma\rangle^f$ = 10.28 fm^2 |Zij76|, |Zij77|

Remarks

With respect to the reaction $^{58}Ni(n,p)^{58}Co$, it is assumed that the ratio of the cross sections for the two reactions leading to metastable state and the ground state respectively is better known than the separate values.
The value of this ratio is taken equal to (3.54±22)/(11.3-3.54) = 0.456 |Ca74|. The value for the sum reaction is 10.85(54) fm^2 |Fa77|. For the indirect reaction one has therefore (10.85×3.54)/11.3 = 3.40 fm^2.
For the direct reaction one has (10.85x7.76)/11.3 = 7.45 fm^2.

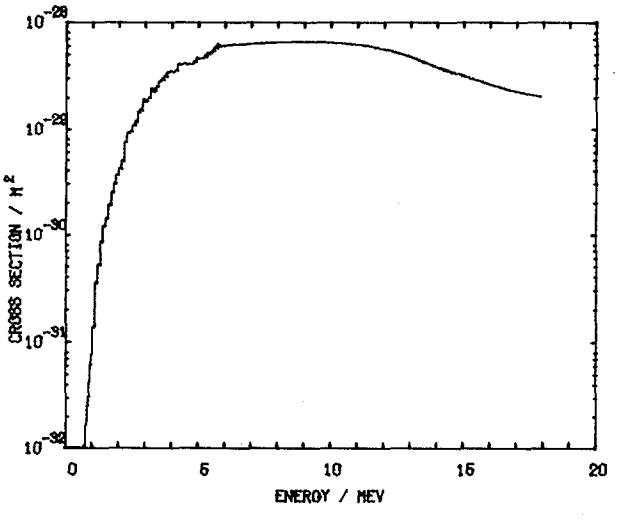
Response data

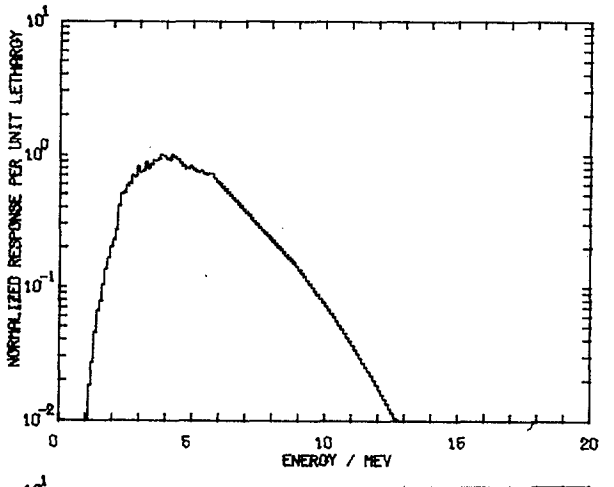
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: NI58(N,P)CO58M

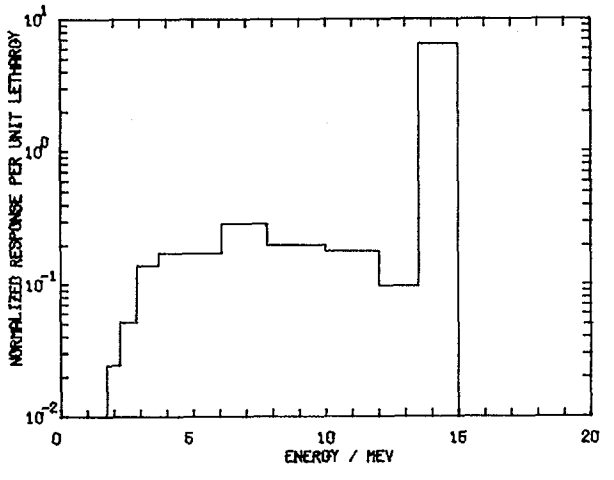
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	2.9E+00	1.4E+01	6.1E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	2.1E+00	8.0E+00	3.0E+00	5.9E+00	3.6E+00	4.9E+00	4.2E+00
235U	2.0E+00	7.6E+00	2.9E+00	5.7E+00	3.5E+00	4.7E+00	4.0E+00
CFRMF	1.9E+00	7.8E+00	2.7E+00	5.7E+00	3.4E+00	4.7E+00	4.0E+00
SIG.SIG.	1.8E+00	7.5E+00	2.6E+00	5.6E+00	3.2E+00	4.5E+00	3.8E+00
MTR	1.9E+00	7.7E+00	2.7E+00	5.6E+00	3.3E+00	4.6E+00	3.9E+00

ALL ENERGY VALUES IN MEV.





MTR



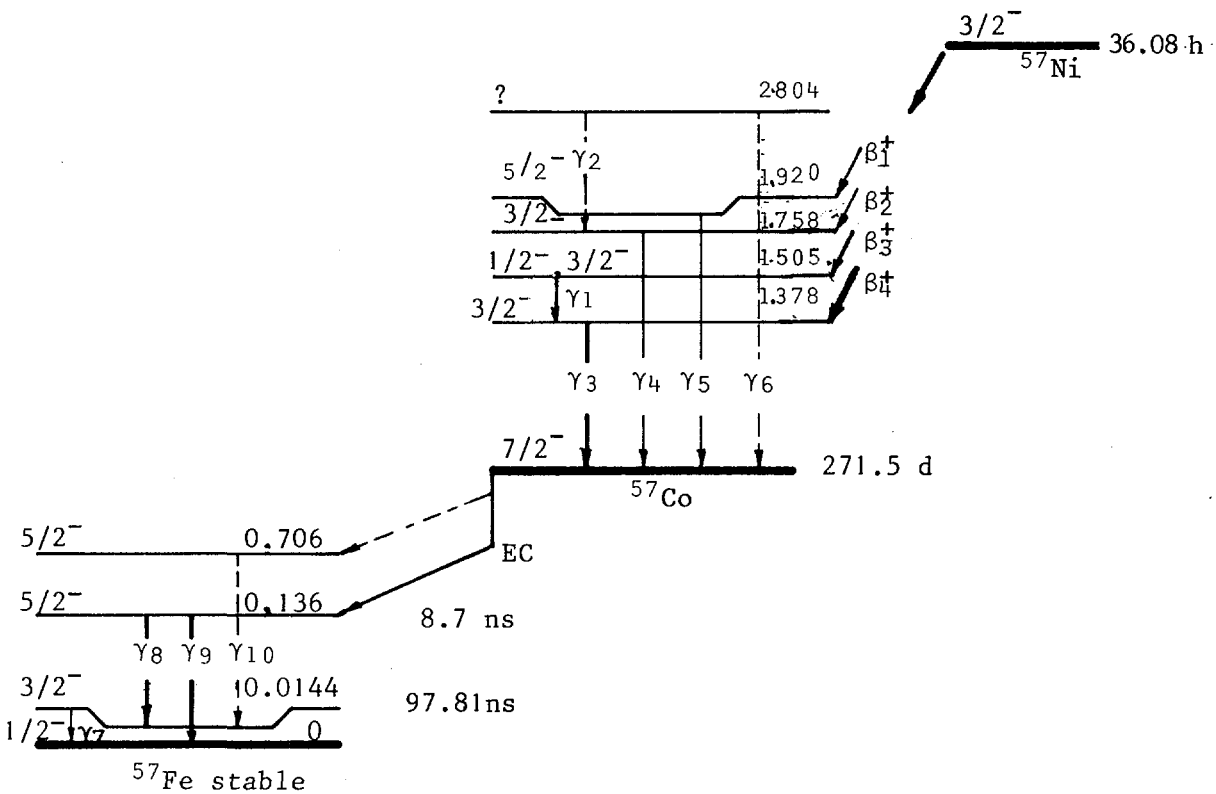
CTR

$^{58}Ni(n,2n)\,^{57}Ni - ^{57}Co$

Material constants

See the reaction $^{58}Ni\ (n,p)^{58}Co$.

Disintegration scheme



Disintegration data |MED78|

^{57}Ni : half-life :		$T_{\frac{1}{2}}$= 36.08(9) h	
decay constant :		λ = 5.3365 x $10^{-6}s^{-1}$	
$E(\beta_1^+)$	max	302(7) keV	
	av	130(3) keV	0.41(5) %
$E(\beta_2^+)$	max	464(7) keV	
	av	197(3) keV	0.86(10)%
$E(\beta_3^+)$	max	716(7) keV	
	av	304(3) keV	5.0 (4) %

$E(\beta_4^+)$ max	843(7) keV	
av	359(3) keV	34.1(9) %
Total β^+	346(3) keV	40.4(10)%

$E(\gamma_1)$	127.19(3) keV	12.9(9) %
$E(\gamma_2)$	1046.40(20)keV	0.125(3)%
$E(\gamma_3)$	1377.59(4) keV	77.9(23)%
$E(\gamma_4)$	1757.48(8) keV	7.1 (7)%
$E(\gamma_5)$	1919.43(8) keV	14.7(10)%
$E(\gamma_6)$	2803.90(20)keV	0.132(3)%

14 weak γ's omitted ($\Sigma P\gamma$ = 0.5 %).

^{57}Co : half-life : $T_{\frac{1}{2}}$ = 271.5(5)d |PTB79| *
decay constant : λ = $295.49 \times 10^{-6}\ s^{-1}$

$E(\gamma_7)$	14.4127(25)	9.54(13)%
$E(\gamma_8)$	122.063(3)	85.59(19)%
$E(\gamma_9)$	136.476(3)	10.61(18)%
$E(\gamma_{10})$	692.00(3)	0.160(5)%

6 weak γ's omitted ($\Sigma P\gamma$ = 0.03%)

Activities induced in nickel

See the reaction ^{58}Ni(n,p)^{58}Co.

Evaluated cross section data

620 group data : |Ma75|, |Zij77|
Integral data :
for a ^{235}U fission spectrum: $\langle\sigma\rangle_c$=0.00254 mb = 0.000254 fm^2 |Zij77|
$\langle\sigma\rangle_m$=0.00577(31)mb=0.000577 fm^2 |Fa78|

Response data

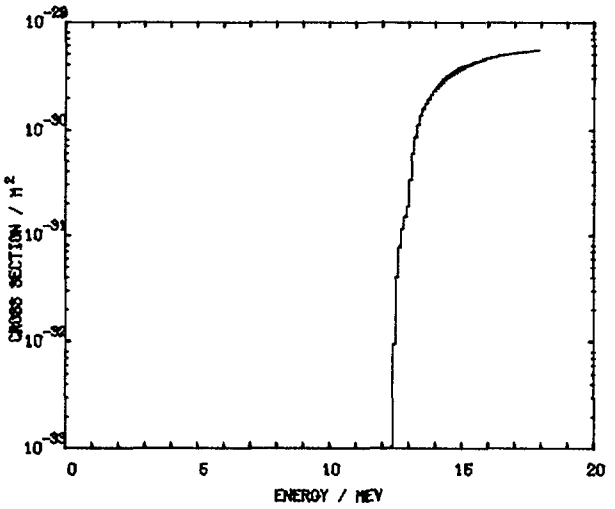
For table and figures see next page.

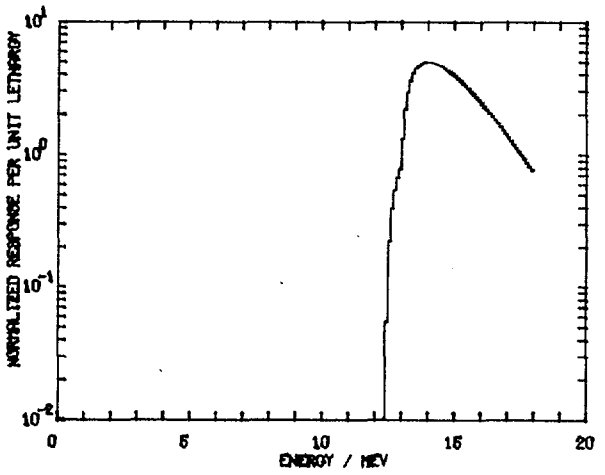
*Remark: It is believed that the value 270.9(6) |MED78| is not correct.

RESPONSE DATA FOR THE REACTION: NI58(N,2N)NI57

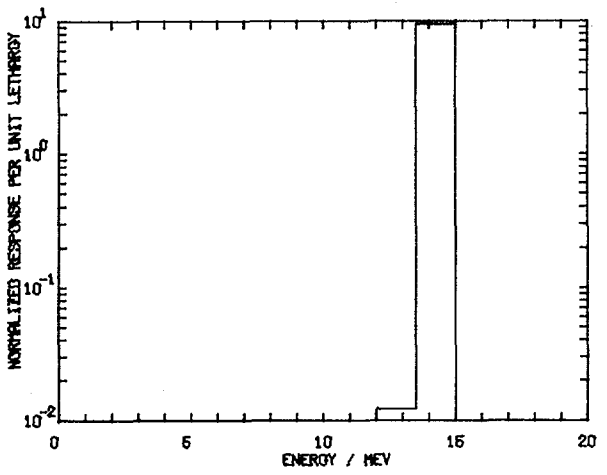
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01
235U	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01
CFRMF	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01
SIG.SIG.	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01
MTR	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{60}Ni\ (n,p)\ ^{60}Co$

Material constants
Activities induced in nickel } see the reaction $^{58}Ni(n,p)^{58}Co$

Disintegration scheme
Disintegration data } see the reaction $^{59}Co(n,\gamma)^{60}Co$

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : for a ^{235}U fission neutron spectrum (Watt representation)

$\langle\sigma\rangle_c$= 2.443 mb= 0.2443 fm^2 |Zij77|

$\langle\sigma\rangle_c$= 2.658 mb= 0.2658 fm^2 |Ma75,2|

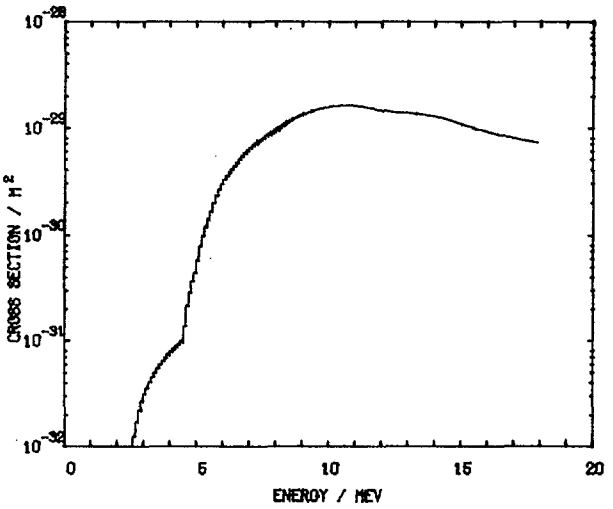
Response data

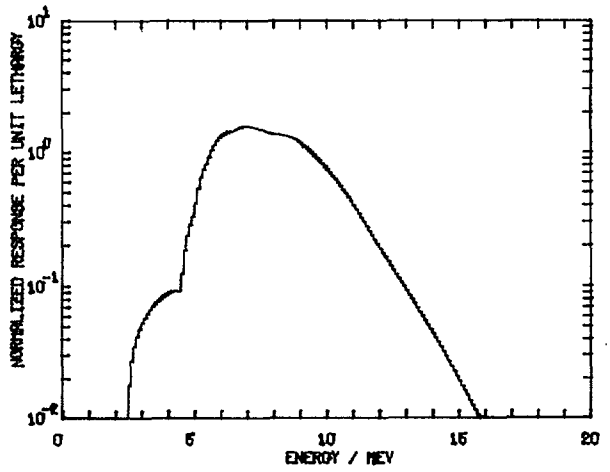
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: NI60(N,P)CO60

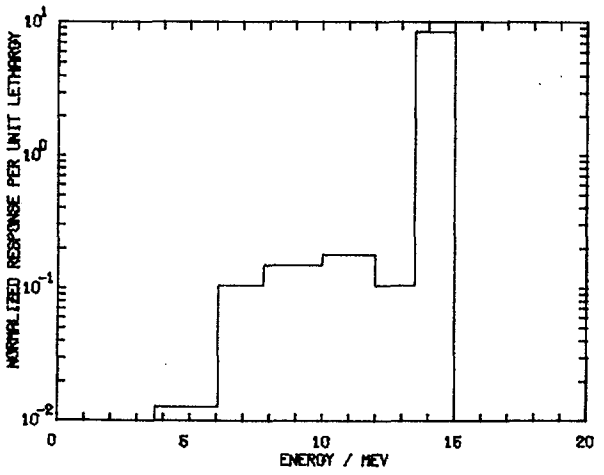
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	7.8E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	4.9E+00	1.1E+01	6.0E+00	9.0E+00	6.6E+00	8.0E+00	7.3E+00
235U	4.8E+00	1.1E+01	5.8E+00	8.7E+00	6.4E+00	7.7E+00	7.0E+00
CFRMF	4.9E+00	1.1E+01	5.9E+00	8.9E+00	6.6E+00	8.0E+00	7.2E+00
SIG.SIG.	4.8E+00	1.1E+01	5.9E+00	8.7E+00	6.5E+00	7.8E+00	7.1E+00
MTR	4.8E+00	1.1E+01	5.9E+00	9.0E+00	6.5E+00	8.0E+00	7.2E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{63}Cu\ (n,\alpha)\ ^{60}Co$

Material constant

Activities induced in copper

} see the reaction $^{63}Cu(n,\gamma)^{64}Cu$

Disintegration scheme and data — see the reaction $^{59}Co(n,\gamma)^{60}Co$

Evaluated cross section

620 group data : |Ma75|, |Zij77|

Integral data : for a ^{235}U fission spectrum

(for a Watt representation) $\langle\sigma\rangle_c$ = 0.3472 mb = 0.03472 fm^2 |Zij77|

$\langle\sigma\rangle$ = 0.168 mb = 0.0168 fm^2 |Ma75,2|

$\langle\sigma\rangle_m$ = 0.500(56) mb=0.0500 fm^2 |Fa78|

Response data

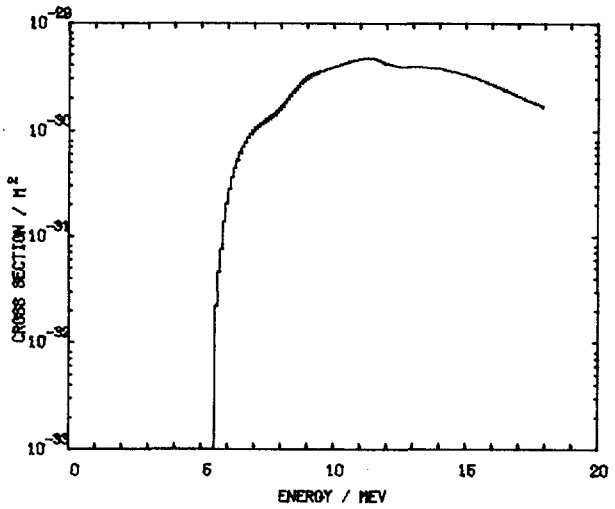
Treshold energy : E_T = 6.8 MeV |Fa78|

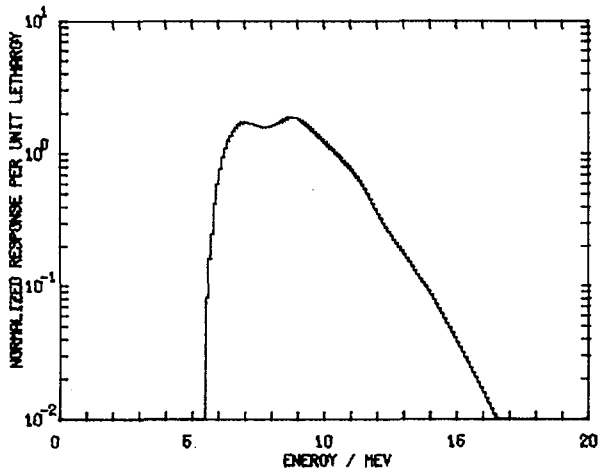
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: CU63(N,A)C060

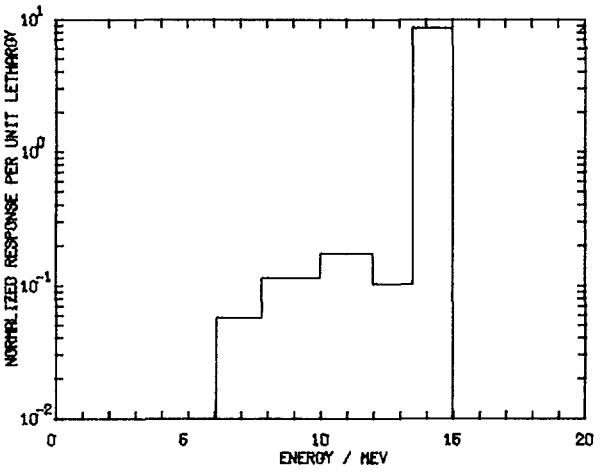
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.0E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	6.1E+00	1.2E+01	6.8E+00	9.9E+00	7.5E+00	8.9E+00	8.2E+00
235U	6.1E+00	1.1E+01	6.7E+00	9.5E+00	7.3E+00	8.7E+00	7.9E+00
CFRMF	6.1E+00	1.2E+01	6.8E+00	9.7E+00	7.4E+00	8.8E+00	8.1E+00
SIG.SIG.	6.1E+00	1.1E+01	6.7E+00	9.5E+00	7.3E+00	8.7E+00	7.9E+00
MTR	6.1E+00	1.2E+01	6.8E+00	9.8E+00	7.5E+00	8.9E+00	8.2E+00

ALL ENERGY VALUES IN MEV.





MTR

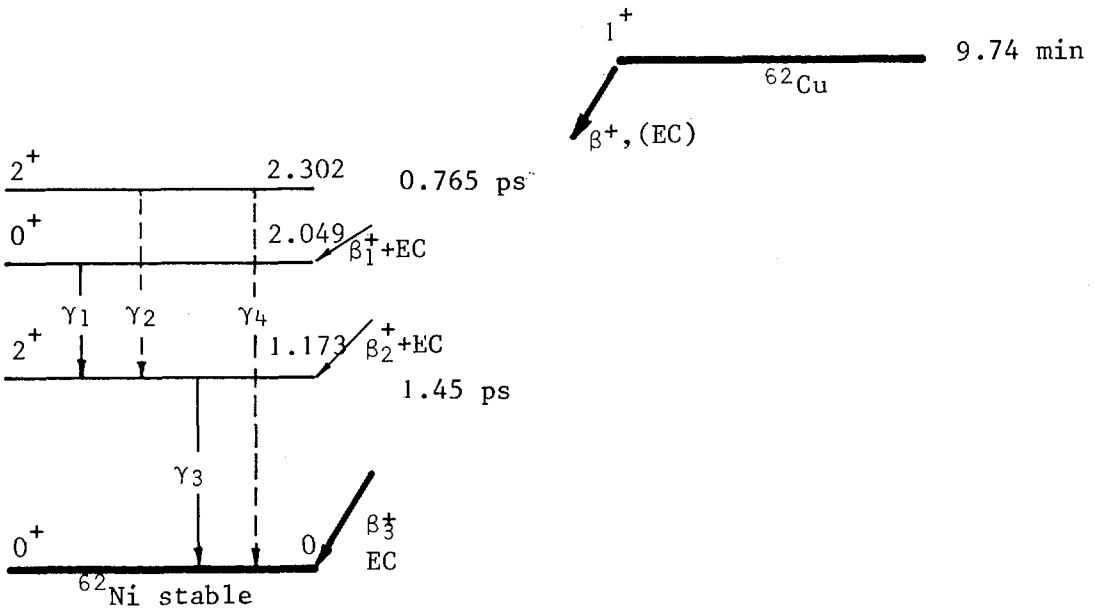


CTR

$^{63}Cu\ (n,2n)\ ^{62}Cu$

Material constants see reaction $^{63}Cu(n,\gamma)^{64}Cu$

Disintegration scheme |Ve74|



Disintegration data |Ve74|

^{62}Cu : half-life : $T_{\frac{1}{2}}$ = 9.74(2) min

decay constant : $\lambda = 1.1861 \times 10^{-3} s^{-1}$

	E (in keV)	P_β(in %)
β_1^+	870(10)	0.77
β_2^+	1750(10)	0.135
β_3^+	2925(7)	97.20

$E(\gamma_1)$	875.71(7) keV	(44(2) †	0.147 %*)
$E(\gamma_2)$	1128.98(10) keV	(9.5(5)†	0.0318 %*)
$E(\gamma_3)$	1173.02(10) keV	(100 †	0.335 %*)
$E(\gamma_4)$	2301.96(8) keV	(12.1(6)†	0.0406 %*)
$E(\gamma_\pm)$	511.0034(14) keV		196.2% maximum

† relative γ-ray emission probability normalized to 100 for 1173.02 keV.

* no correction for internal conversion of the gamma rays has been applied.

Activities induced in copper

See the reaction $^{63}Cu(n,\gamma)^{64}Cu$

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : for a ^{235}U fission spectrum:

(for a Watt representation)* : $\langle\sigma\rangle_c$=0.08464mb = 0.00864fm^2 |Zij77|

(for a Grundl modified represent.)*: $\langle\sigma\rangle_c$=0.09151mb = 0.009151fm^2 (App.5)

$\langle\sigma\rangle_m$=0.122(12)mb=0.0122fm^2 |Fa78|

$\langle\sigma\rangle_c$=0.464 mb = 0.0464fm^2 |Ma75,2|

for a ^{252}Cf fission spectrum : $\langle\sigma\rangle_m$ = 0.30(3) mb = 0.030 fm^2 |Fa78|

Response data

Threshold energy : E_T = 12.4 MeV |Fa78|

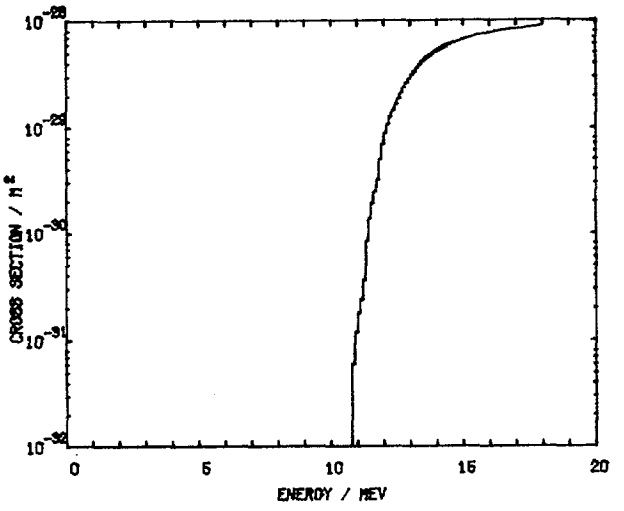
For table and figures see next page.

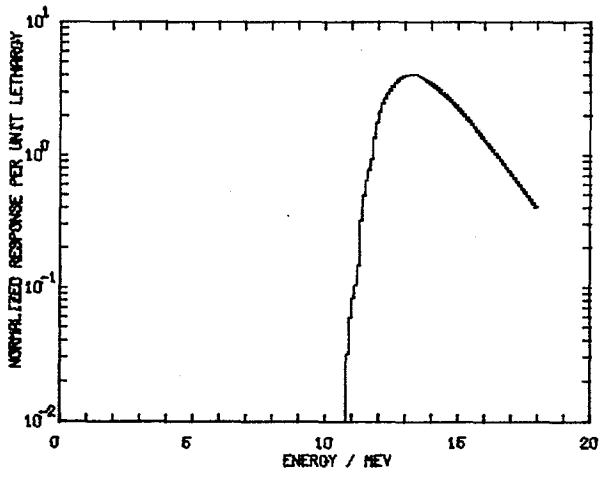
* See appendix 2.

RESPONSE DATA FOR THE REACTION: CU63(N,2N)CU62

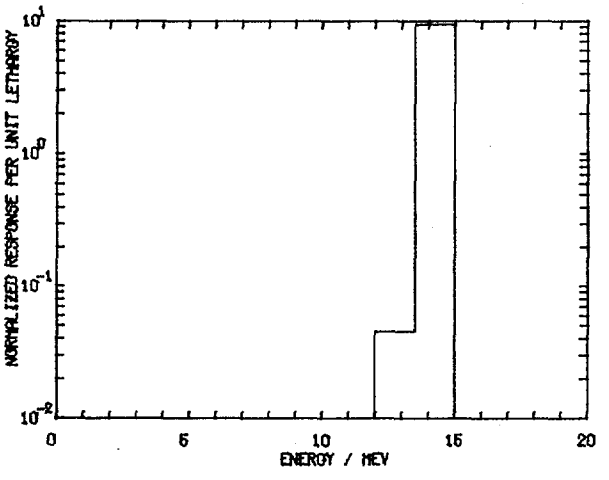
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.2E+01	1.7E+01	1.3E+01	1.5E+01	1.3E+01	1.4E+01	1.4E+01
235U	1.2E+01	1.6E+01	1.3E+01	1.5E+01	1.3E+01	1.4E+01	1.4E+01
CFRMF	1.2E+01	1.7E+01	1.3E+01	1.5E+01	1.3E+01	1.4E+01	1.4E+01
SIG.SIG.	1.2E+01	1.7E+01	1.3E+01	1.5E+01	1.3E+01	1.4E+01	1.4E+01
MTR	1.2E+01	1.7E+01	1.3E+01	1.5E+01	1.3E+01	1.4E+01	1.4E+01

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{63}Cu(n,\gamma)^{64}Cu$

Material constants

Relative atomic mass of element: $A_r(Cu) = 63.546(3)$ |Ho79|

Mass density : $\rho = 8.96\ Mg.m^{-3}$ |We79|

Melting point : $T = 1356.55\ K = 1083.4(2)^{o}C$ |We79|

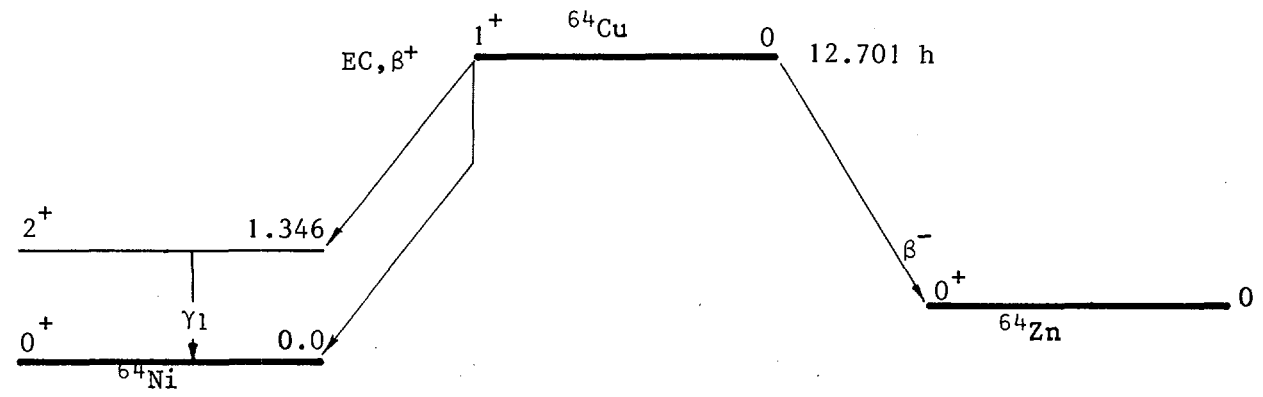
Number of atoms per unit mass : $N_m = 9.477\times10^{24}kg^{-1}$

Number of atoms per unit volume: $N_v = 84.92\times10^{27}m^{-3}$

\+ Isotopic mole fractions : $x(^{63}Cu) = 69.17(2)\ \%$ |Ho79|

\+ $x(^{65}Cu) = 30.83(2)\ \%$

Disintegration scheme



Disintegration data |MED78|

^{64}Cu: half-life = 12.701(2) h

$\lambda = 15.160\times10^{-6}s^{-1}$

intensity $EC+\beta^+$ 62.8(4)%

\+ $E(\beta^+)$ max 652.9(8) keV

\+ av 278.1(11) keV (17.87(18)%)

\+ $E(\beta^-)$ max 578.2(15) keV

\+ av 190.3(5) keV (37.2(4)%)

\+ $E(\gamma_1)$ 1345.9(3) keV (0.49(4)%)

\+ $E(\gamma_\pm)$ 511.0034(14) keV (35.74% maximum)

Activities induced in copper

$^{63}Cu(n,\gamma)^{64}Cu$

$T_{\frac{1}{2}}$ = 12.701(2) h |MED78| σ_{act} = 450(10) fm^2 |Mu73|

I = 490(40) fm^2 |Mu73| I' = 279(18) fm^2 |Ry74|

g value Westcott convention 1.00

s_o value Westcott convention 0.6996

+	$^{65}Cu(n,\gamma)^{66}Cu$	$T_{\frac{1}{2}}$ = 5.10 min	|Wa77|	σ_{act} = 217(3) fm^2	|Mu73|
+	$^{66}Cu(n,\gamma)^{67}Cu$	$T_{\frac{1}{2}}$ = 61.7 h	|Wa77|	σ_{act} = 13500(1000) fm^2	|Mu73|
+	$^{63}Cu(n,\alpha)^{60}Co$*	$T_{\frac{1}{2}}$ = 5.271 a	|MED78|	$\langle\sigma\rangle$ = 0.0500(56) fm^2	|Fa76|
+	$^{63}Cu(n,2n)^{62}Cu$	$T_{\frac{1}{2}}$ = 9.74 min	|Wa77|	$\langle\sigma\rangle$ = 0.0124(11) fm^2	|Ca74|
+	$^{65}Cu(n,p)^{65}Ni$	$T_{\frac{1}{2}}$ = 2.520 h	|Ko77|	$\langle\sigma\rangle$ = 0.048(8) fm^2	|Ca74|
	$^{65}Cu(n,2n)^{64}Cu$	$T_{\frac{1}{2}}$ = 12.701 h	|MED78|	$\langle\sigma\rangle$ = 0.0124(11) fm^2	|Ca74|

Evaluated cross section data

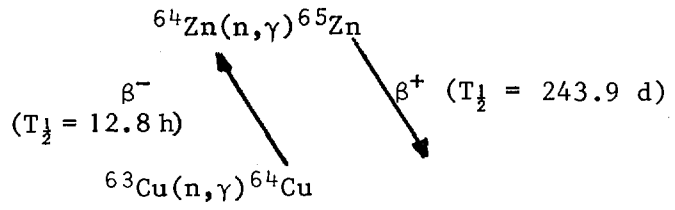
620 group data : |Ma75|, |Zij77|

Integral data : $g.\sigma_o$ = 451.8 fm^2 |Zij77|

I = 538.6 fm^2

*Remark:

The following competing reactions occur



The nuclide ^{65}Zn emits gamma rays of 1.115 MeV which is close to the energies 1.17 MeV and 1.33 MeV of the gamma rays emitted by ^{60}Co.
This fact might cause problems, especially when scintillation counting equipment is used.

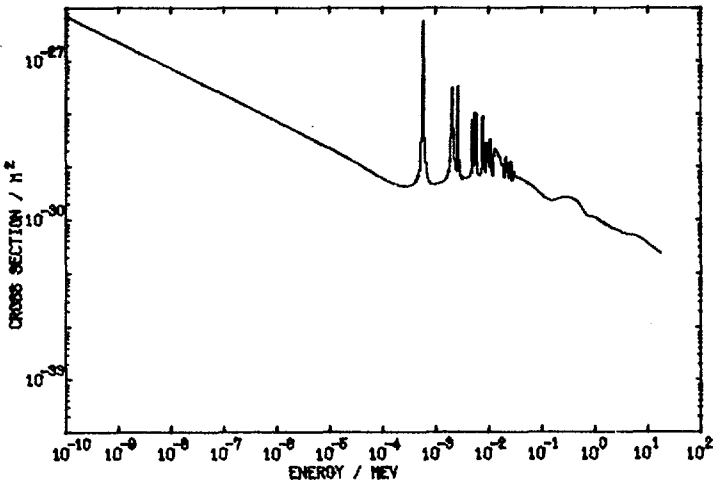
Response data

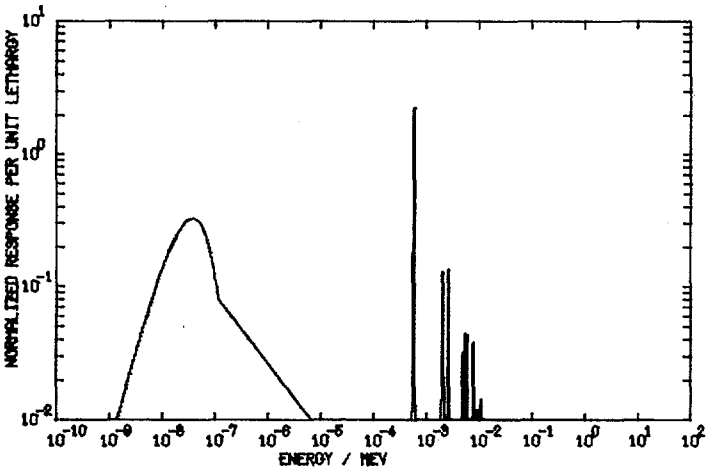
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: CU63(N,G)CU64

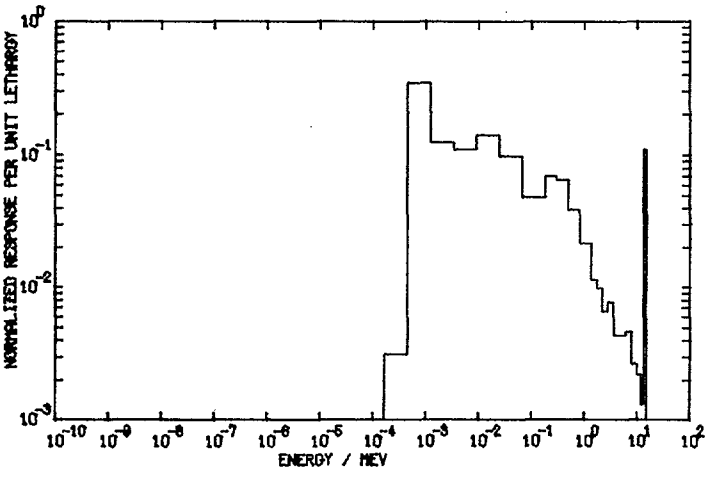
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	4.5E-04	5.0E-01	4.5E-04	2.5E-02	4.5E-04	9.1E-03	3.4E-03
252CF	6.9E-02	4.2E+00	3.2E-01	2.1E+00	5.3E-01	1.3E+00	8.8E-01
235U	5.8E-02	3.9E+00	2.8E-01	2.0E+00	4.8E-01	1.2E+00	8.0E-01
CFRMF	5.8E-04	7.2E-01	5.8E-04	2.4E-01	2.0E-03	5.3E-02	9.2E-03
SIG.SIG.	5.8E-04	9.2E-01	5.8E-04	3.2E-01	7.6E-03	1.2E-01	2.7E-02
MTR	5.5E-09	1.2E-03	1.7E-08	1.4E-06	2.8E-08	8.4E-08	4.5E-08

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{65}Cu\ (n,2n)\ ^{64}Cu$

Material constants

Disintegration scheme and data

Activities induced in copper

} See reaction $^{63}Cu(n,\gamma)^{64}Cu$

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : for a ^{235}U fission spectrum

(for a Watt representation) $\langle\sigma\rangle_c$ = 0.2976 mb = 0.02976 fm^2 |Zij77|

Response data

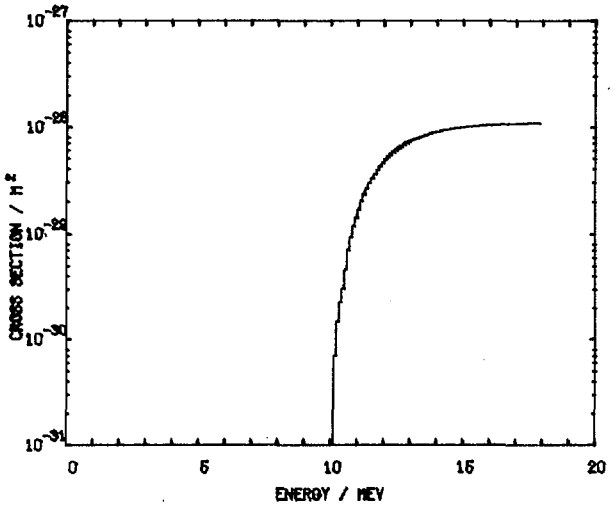
Threshold energy = E_T = 10.06 MeV |Ca74|

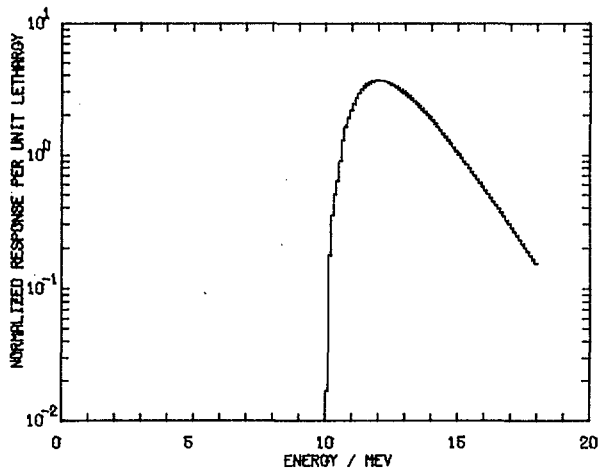
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: CU65(N,2N)CU64

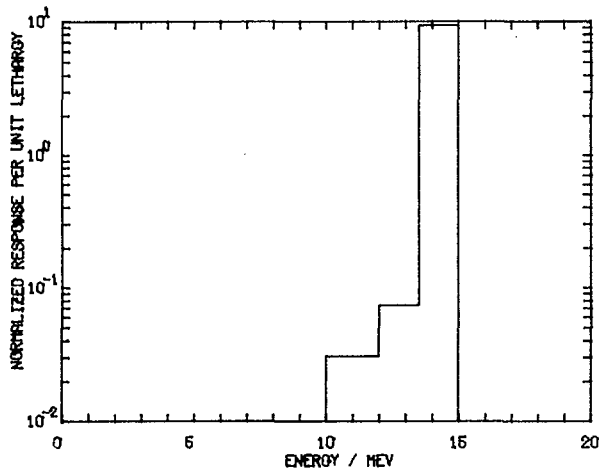
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.1E+01	1.6E+01	1.1E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01
235U	1.1E+01	1.5E+01	1.1E+01	1.4E+01	1.2E+01	1.3E+01	1.2E+01
CFRMF	1.1E+01	1.6E+01	1.1E+01	1.4E+01	1.2E+01	1.3E+01	1.3E+01
SIG.SIG.	1.1E+01	1.6E+01	1.1E+01	1.4E+01	1.2E+01	1.3E+01	1.2E+01
MTR	1.1E+01	1.6E+01	1.1E+01	1.4E+01	1.2E+01	1.3E+01	1.2E+01

ALL ENERGY VALUES IN MEV.





MTR



CTR

$^{64}Zn\ (n,p)\ ^{64}Cu$

Material constants :

Relative atomic mass of element	$A_r(Zn)$	= 65.38(1) |Ho79|,	|We79|
Mass density	ρ	= 7.133 $Mg.m^{-3}$	
Melting point	T	= 146.43 K = 419.58 °C	
Number of atoms per unit mass	N_m	= $9.212\times10^{24} kg^{-1}$	
Number of atoms per unit volume	N_v	= $65.71\times10^{27} m^{-3}$	
Isotopic mole fractions	$x(^{64}Zn)$	= 48.6(1) %	|Ho79|
	$x(^{65}Zn)$	= 27.9(1) %	
	$x(^{67}Zn)$	= 4.1(1) %	
	$x(^{68}Zn)$	= 18.8(1) %	
	$x(^{70}Zn)$	= 0.6(1) %	

Disintegration scheme and data

see the reaction $^{63}Cu(n,\gamma)^{64}Cu$

Activities induced in zinc

$^{64}Zn(n,p)^{64}Cu$; $T_{\frac{1}{2}}$ = 12.701(2)h	|MED78|	; $\langle\sigma\rangle$= 29.9(16)mb= 2.99 fm^2	|Fa77|
$^{64}Zn(n,\gamma)^{65}Zn$; $T_{\frac{1}{2}}$ = 243.9(1) d	|MED78|	; σ_0 = 0.78(2)b = 78 fm^2	|Mu73|
$^{64}Zn(n,2n)^{63}Zn$; $T_{\frac{1}{2}}$ = 38.1 min	|Au75|	; $\langle\sigma\rangle$= $0.040(^{+28}_{-16})$mb=0.004 fm^2	|Ca74|
$^{66}Zn(n,p)^{66}Cu$; $T_{\frac{1}{2}}$ = 5.10 min	|Wa77|	; $\langle\sigma\rangle$= 0.62(11)mb= 0.062 fm^2	|Ca74|
$^{67}Zn(n,p)^{67}Cu$; $T_{\frac{1}{2}}$ = 61.7 h	|Wa77|	; $\langle\sigma\rangle$= 1.07(4) mb= 0.107 fm^2	|Ca74|
$^{68}Zn(n,p)^{68}Cu^m$; $T_{\frac{1}{2}}$ = 3.8 min	|Wa77|	; $\langle\sigma\rangle$=0.0156(25)mb=0.00156 fm^2	|Ca74|
$^{68}Zn(n,p)^{68}Cu$; $T_{\frac{1}{2}}$ = 31 s	|Wa77|	;	
$^{68}Zn(n,\gamma)^{69}Zn^m$; $T_{\frac{1}{2}}$ = 13.76(3)h	|Ko77|	; σ_0 =0.072(4) b = 7.2 fm^2	|Mu73|
$^{68}Zn(n,\gamma)^{69}Zn$; $T_{\frac{1}{2}}$ = 57 min	|Wa77|	; σ_0 = 1.0(1)b = 100 fm^2	|Mu73|
$^{68}Zn(n,\alpha)^{65}Ni$; $T_{\frac{1}{2}}$ = 2.520 h	|Wa77|	; $\langle\sigma\rangle$= 0.074(6)mb=0.0074 fm^2	|Ca74|
$^{70}Zn(n,\gamma)^{71}Zn^m$; $T_{\frac{1}{2}}$ = 3.97 h	|Wa77|	; σ_0 = 8.7(5) mb = 0.87 fm^2	|Mu73|
$^{70}Zn(n,\gamma)^{71}Zn$; $T_{\frac{1}{2}}$ = 2.4 min	|Wa77|	; σ_0 = 83(5) mb = 8.3 fm^2	|Mu73|

Evaluated cross section data

620 group data : \|La75\|, \|Zij77\|

Integral data : For a ^{235}U fission spectrum :

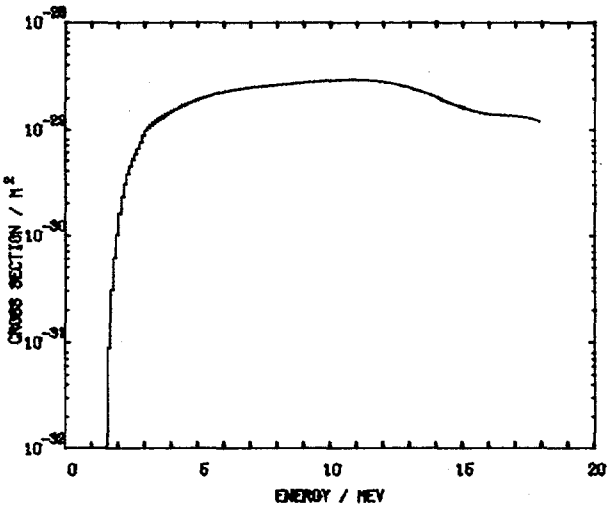
$\langle\sigma\rangle_c$= 42.94 mb = 4.294 fm^2 \|Zij77\|

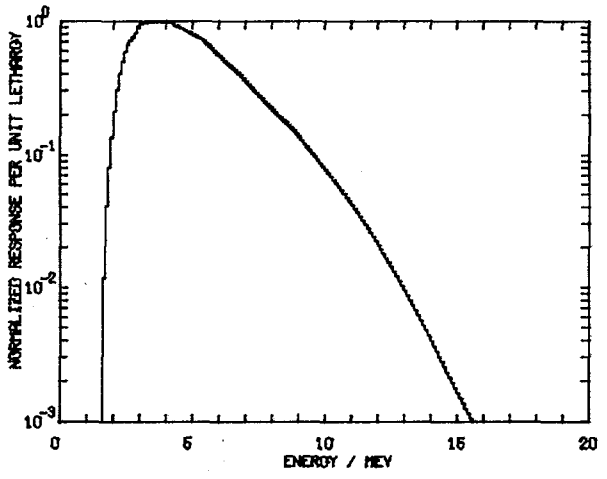
$\langle\sigma\rangle_m$= 29.9(16) mb=2.99 fm^2 \|Fa78\|

RESPONSE DATA FOR THE REACTION: 64ZN(N,P)64CU

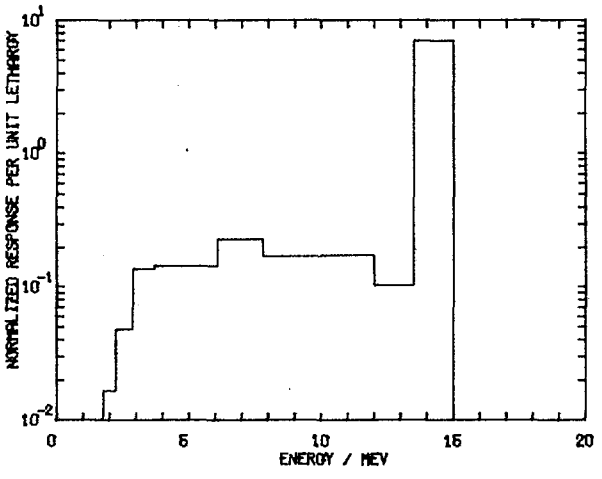
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	2.9E+00	1.4E+01	7.8E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	2.3E+00	8.1E+00	3.0E+00	5.9E+00	3.5E+00	4.9E+00	4.1E+00
235U	2.3E+00	7.6E+00	2.9E+00	5.6E+00	3.4E+00	4.7E+00	4.0E+00
CFRMF	2.2E+00	7.8E+00	2.9E+00	5.6E+00	3.4E+00	4.6E+00	3.9E+00
SIG.SIG.	2.2E+00	7.5E+00	2.8E+00	5.6E+00	3.3E+00	4.5E+00	3.8E+00
MTR	2.2E+00	7.7E+00	2.8E+00	5.5E+00	3.3E+00	4.5E+00	3.9E+00

ALL ENERGY VALUES IN MEV.





MTR



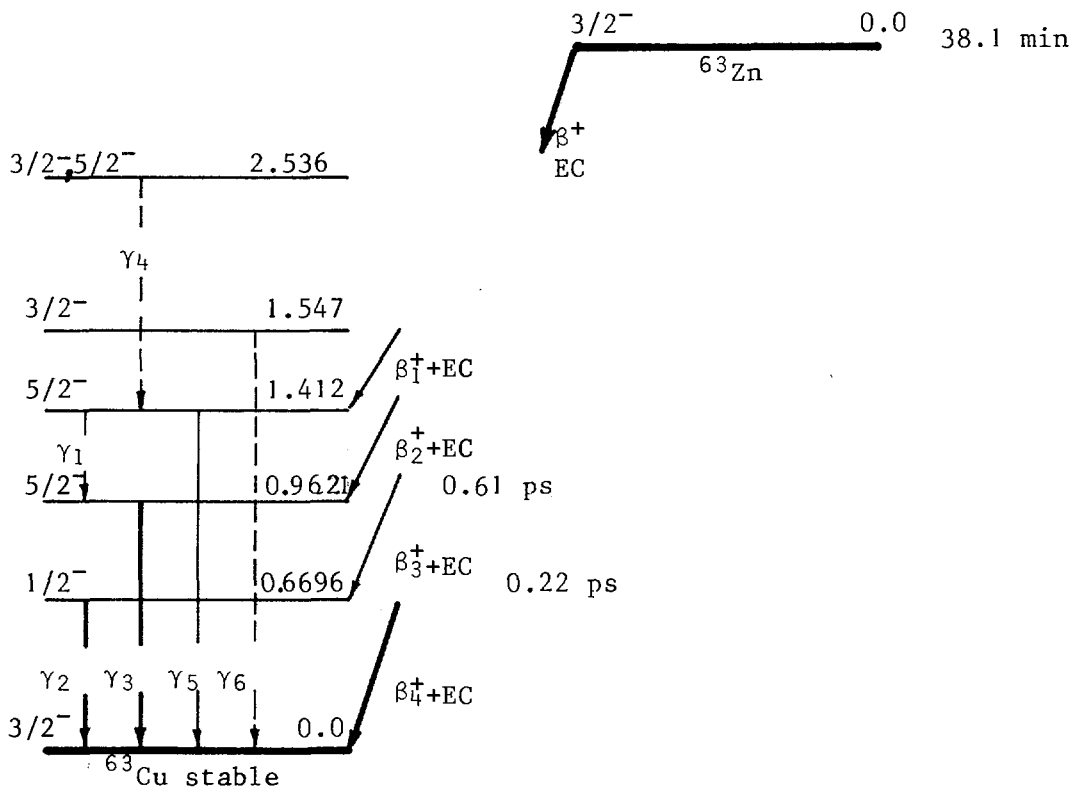
CTR

$^{64}Zn\ (n,2n)\ ^{63}Zn$

Material constants

see reaction $^{64}Zn(n,p)^{64}Cu$

Disintegration scheme |Au75|



Disintegration data |Au75|

^{63}Zn : half-life : $T_{\frac{1}{2}}$ = 38.1(3) min

decay constant : $\lambda = 3.0321 \times 10^{-4} s^{-1}$

	E_{β^+} (in keV)	P_{β^+} (in %)	P_{EC} (in %)
β_1^+	932	0.51	0.44
β_2^+	1400(30)	5.1	1.2
β_3^+	1690(30)	7.2	0.94
β_4^+	2340(20)	80.0	3.7

$Q^+ = E\ (\beta^+) + 2\ mc^2 = 3365.3(27)$ keV

$E(\gamma_1)$	449.93(5) keV	(2.88(20)	†;	0.24 %)
$E(\gamma_2)$	669.62(5) keV	(100	†;	8.4 %)
$E(\gamma_3)$	962.06(4) keV	(79(4)	†;	6.6 %)
$E(\gamma_4)$	1123.72(7) keV	(1.35(14)	†;	0.113%)
$E(\gamma_5)$	1412.08(5) keV	(9.1(4)	†;	0.76 %)
$E(\gamma_6)$	1547.04(6) keV	(1.49(6)	†;	0.125%)

$E(\gamma\pm)$ 511.0034(14) keV (185.6% maximum)

† relative γ-ray emission probability normalized to 100 for 669.62 keV.

Absolute γ-ray emission probabilities are calculated using P (669.62γ) / $P(\beta^+)$ = 0.0914(36), theoretical (EC/β^+)-ratios, and requiring an intensity balance at each level and a total of 100 $(EC+\beta^++\gamma)$-transitions to the ground state.

This gives $P\gamma(\%)/P\gamma(rel)$ = 0.084(4) if $P\gamma(rel)$ = 100 for the 669.62 keV γ.

Activities induced in zinc

see the reaction $^{64}Zn(n,p)^{64}Cu$.

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : for a ^{235}U fission spectrum

(for a Watt representation*) : $\langle\sigma\rangle_c$= 0.01657 mb=0.001657 fm^2 |Zij77|

(for a Grundl modified representation*): $\langle\sigma\rangle_c$=0.01839 mb=0.001839 fm^2 (App.5)

Response data

Threshold energy : E_T = 12.04 MeV |Ca74|

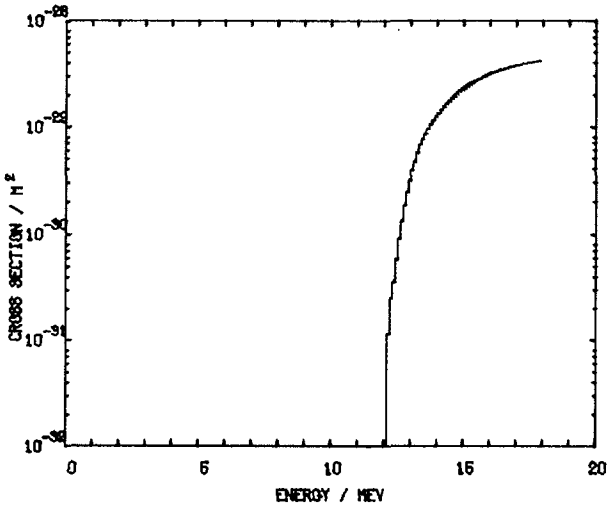
For table and figures see next page.

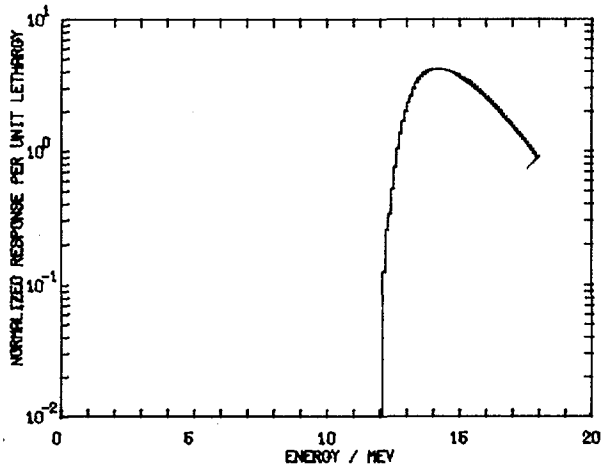
* See appendix 2.

RESPONSE DATA FOR THE REACTION: 64ZN(N,2N)63ZN

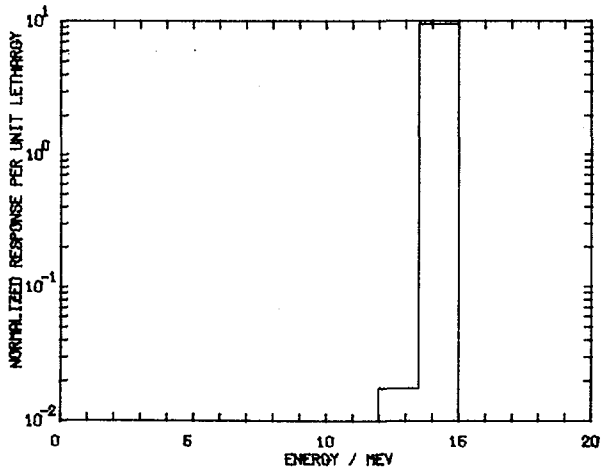
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01
235U	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01
CFRMF	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01
SIG.SIG.	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01
MTR	1.3E+01	1.7E+01	1.4E+01	1.6E+01	1.4E+01	1.5E+01	1.5E+01

ALL ENERGY VALUES IN MEV.





MTR



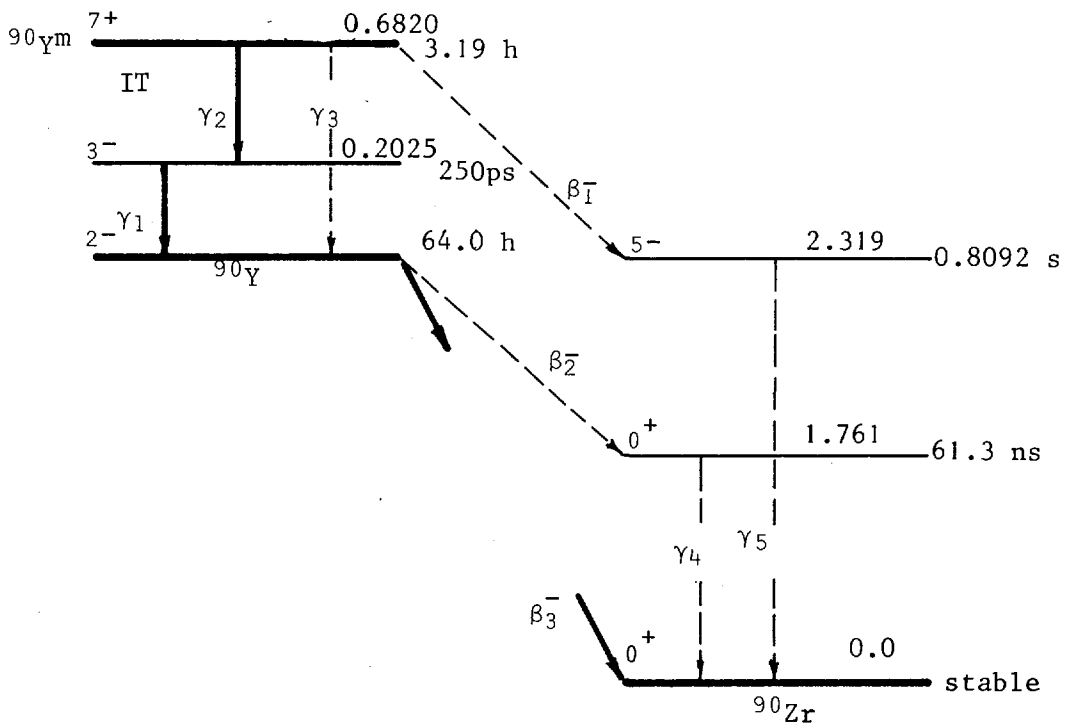
CTR

$^{90}Zr\,(n,p)\,^{90}Y$

Material constants

See reaction $^{90}Zr(n,2n)^{89}Zr$

Disintegration scheme |Ko75,1|



Disintegration data |Ko77|

$^{90}Y^m$	half-life	: $T_{\frac{1}{2}}$ = 3.19(1) h		
	decay constant	: $\lambda = 6.0358 \times 10^{-5} s^{-1}$		
	$E(\beta_1^-)$ max 642.1 keV	≤0.008 %		
	$E(\gamma_1)$ 202.51(3) keV	96.58(18) %		
	$E(\gamma_2)$ 479.53(4) keV	90.71(7) %		
	$E(\gamma_3)$ 682 keV	0.36(8) %		
^{90}Y	half-life	: $T_{\frac{1}{2}}$ = 64.0(1) h		
	decay constant	: $\lambda = 3.0085 \times 10^{-6} s^{-1}$		

|Ko75,1|

$E(\beta_2^-)$	max	518.5	keV	0.0115%	|Ko75,1|
$E(\beta_3^-)$	max	2276(3)	keV		
	av	931.0(12)	keV	99.984(3) %	
$E(\gamma_4)$		1760.7	keV	0.0115%	}|Ko75,1|
$E(\gamma_5)$		2319.10	keV	$\leq$0.008 %	

Activities induced in zirconium

see the reaction $^{90}Zr(n,2n)^{89}Zr$

Evaluated cross section data

620 group data : |Ma75| , |Zij77|

Integral data : for a ^{235}U fission spectrum

(for a Watt representation): $\langle\sigma\rangle_c$ = 0.3567 mb = 0.03567 fm^2 |Zij77|

$\langle\sigma\rangle$ = 0.18(6)mb = 0.018 fm^2 |Ca74|

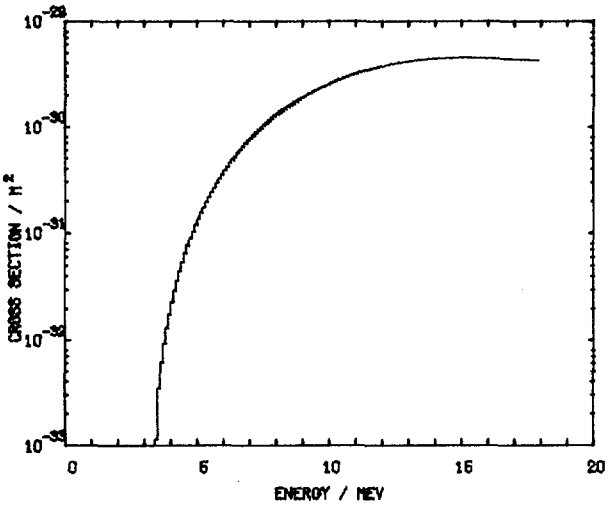
Response data

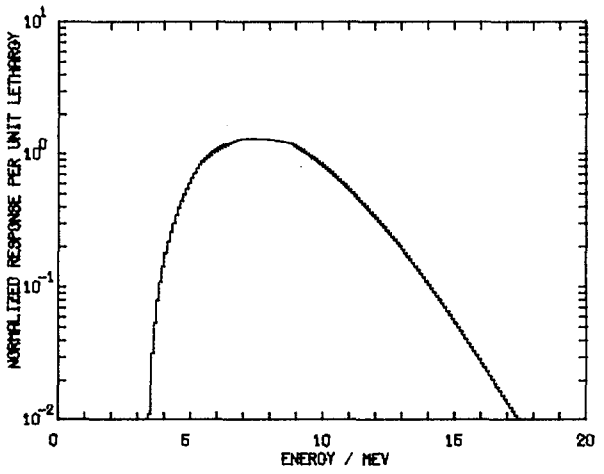
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: 90ZR(N,P)90Y

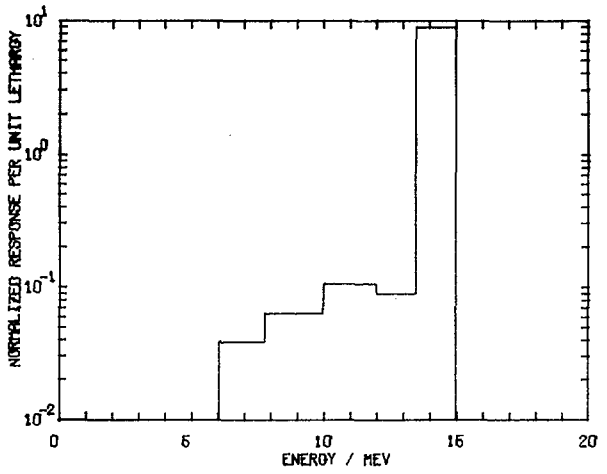
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.2E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	4.6E+00	1.2E+01	5.8E+00	9.5E+00	6.6E+00	8.3E+00	7.4E+00
235U	4.5E+00	1.1E+01	5.6E+00	9.0E+00	6.3E+00	7.9E+00	7.0E+00
CFRMF	4.6E+00	1.2E+01	5.7E+00	9.3E+00	6.5E+00	8.2E+00	7.3E+00
SIG.SIG.	4.6E+00	1.1E+01	5.7E+00	9.1E+00	6.4E+00	8.0E+00	7.1E+00
MTR	4.5E+00	1.2E+01	5.7E+00	9.4E+00	6.5E+00	8.2E+00	7.3E+00

ALL ENERGY VALUES IN MEV.





MTR



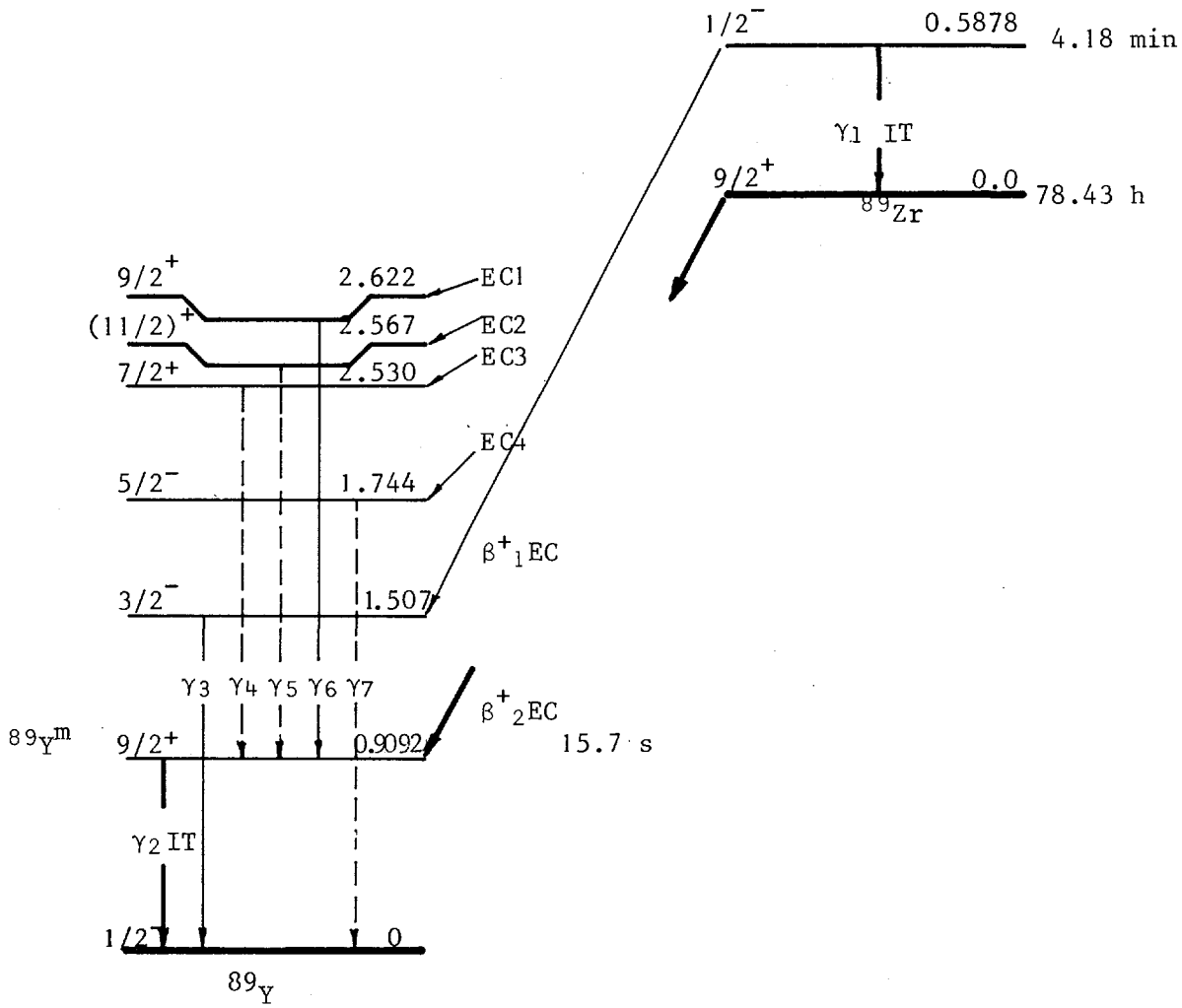
CTR

$^{90}Zr(n,2n)\,^{89}Zr$

Material constants

Relative atomic mass of element	: $A_r(Zr)$	= 91.22(1) |Ho79|,	|We79|
Mass density	: ρ	= 6.506 $Mg.m^{-3}$	
Melting point	: T	= 1578.85 K = 1852(2) °C	
Number of atoms per unit mass	: N_m	= $6.602\times10^{24}kg^{-1}$	
Number of atoms per unit volume	: N_v	= $42.95\times10^{27}m^{-3}$	
Isotopic mole fractions	: $x(^{90}Zr)$	= 51.5(1) %	Ho79
	$x(^{91}Zr)$	= 11.2(1) %	
	$x(^{92}Zr)$	= 17.1(1) %	
	$x(^{94}Zr)$	= 17.4(1) %	
	$x(^{96}Zr)$	= 2.8(1) %	

Disintegration scheme |Ko75,2|



Disintegration data |Ko75,2|

$^{89}Zr^{m}$ half-life : $T_{\frac{1}{2}}$ = 4.18(1) min
decay constant : λ = 2.7637×10^{-3} s^{-1}

(β_1^+,EC): $E(\beta_1^+)$ max 890(3) keV; $E(\beta_1^+)$ av 390.4(13) keV;
P_{β^+} 1.341%; P_{EC} 4.70%

$E(\gamma_1)$ 587.8(1) keV (89.50%)
$E(\gamma_3)$ 1507.4(5) keV (6.04(6)%)
$E(\gamma_{\pm})$ 511.0034 keV (3.02% maximum)

^{89}Zr half-life : $T_{\frac{1}{2}}$ = 78.43(8) h
decay constant : λ = $2.45494\times10^{-6}s^{-1}$

(β_2^+,EC): $E(\beta_2^+)$ max 900(3) keV; $E(\beta_2^+)$ av 394.9(13) keV;
P_{β^+} 22.64(19)%; P_{EC} 76.29%

$E(\gamma_4)$ 1620.8(2) keV (0.071(7)%)
$E(\gamma_5)$ 1657.3(2) keV (0.100(1)%)
$E(\gamma_6)$ 1712.9(8) keV (0.77 (7)%)
$E(\gamma_7)$ 1744.5(2) keV) (0.130(1)%)

$E(\gamma^{\pm})$ 511.0034 keV

$^{89}Y^{m}$ half-life : $T_{\frac{1}{2}}$ = 15.7 s |Wa77|
decay constant : λ = $4.4150\times10^{-2}s^{-1}$
$E(\gamma_2)$ 909.2(1) keV (99.870(10)%)

Activities induced in zirconium

$^{90}Zr\ (n,p)^{90}Y$; $T_{\frac{1}{2}}$ = 64.0 h	|Ko77|	;$\langle\sigma\rangle$=0.18(6)mb=0.018fm^2	|Ca74|
$^{90}Zr\ (n,2n)^{89}Zr$;$T_{\frac{1}{2}}$ = 78.43 h	|Ko75,2|	;$\langle\sigma\rangle$=0.076(19)mb=0.0076fm^2	|Ca74|
$^{90}Zr\ (n,\gamma)^{91}Zr$; stable		;σ_0 =0.10(7) b=10fm^2	} |Mu73|
		; I =0.20(3) b=20fm^2	
$^{92}Zr\ (n,\gamma)^{93}Zr$; $T_{\frac{1}{2}}$ = 1.5x10^6 a	|Wa77|	;σ_0 =0.26(8) b=26fm^2	|Mu73|
$^{92}Zr\ (n,\alpha)^{89}Sr$; $T_{\frac{1}{2}}$ = 50.52 d	|Wa77|	;$\langle\sigma\rangle$=0.014(4)mb=0.0014fm^2	|Ca74|
$^{94}Zr\ (n,\gamma)^{95}Zr$; $T_{\frac{1}{2}}$ = 64.0 d	|Wa77|	;σ_0 =0.056(4)b=5.6fm^2	} |Mu73|
		I =0.30(3) b=30fm^2	
$^{96}Zr\ (n,\gamma)^{97}Zr$; $T_{\frac{1}{2}}$ = 16.8 h	|Wa77|	;σ_0 =0.017(3) b= 1.7fm^2	
		I =5.0(4) b =500fm^2	

Evaluated cross section data

620 group data : |Ma75| , |Zij77|

Integral data : for a ^{235}U fission spectrum:

(for a Watt representation*)	$\langle\sigma\rangle_c$=0.07953 mb=0.007953fm^2	|Zij77|
	$\langle\sigma\rangle_m$=0.247(17)mb=0.0247fm^2	|Fa78|
(for a Grundl modified represent.*)	$\langle\sigma\rangle$=0.08714 mb=0.008714fm^2	(App.5)

Response data

Threshold energy : E_T = 12.07 MeV |Ca74|

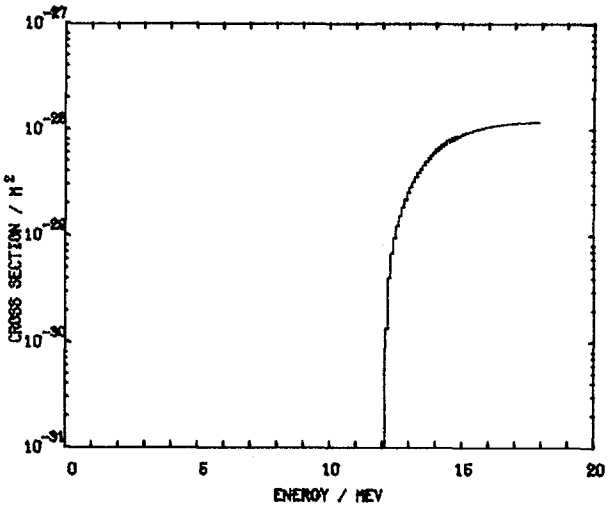
For table and figures see next page.

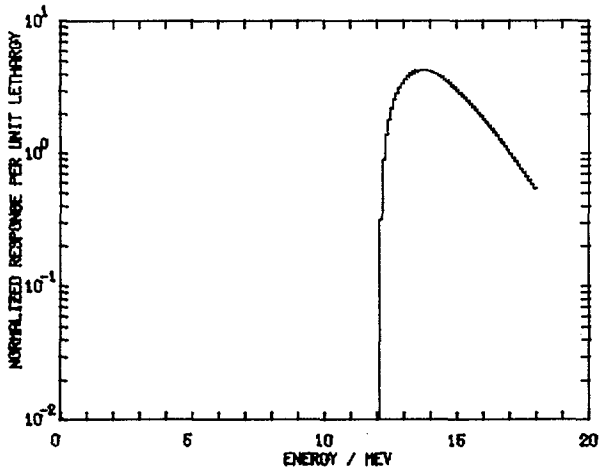
* See appendix 2.

RESPONSE DATA FOR THE REACTION: ZR90(N,2N)ZR89

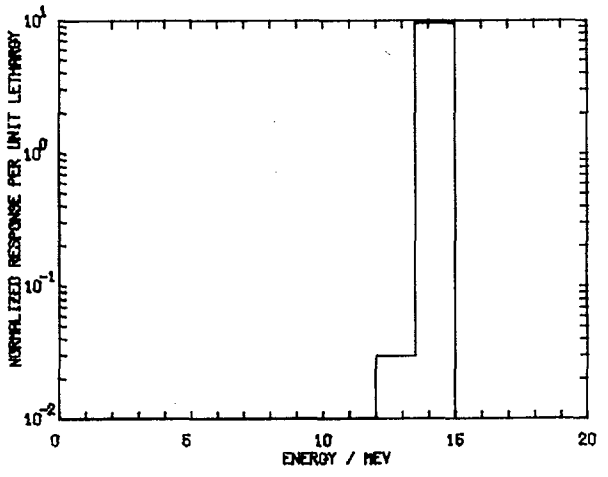
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.3E+01	1.7E+01	1.3E+01	1.6E+01	1.4E+01	1.5E+01	1.4E+01
235U	1.3E+01	1.7E+01	1.3E+01	1.5E+01	1.4E+01	1.5E+01	1.4E+01
CFRMF	1.3E+01	1.7E+01	1.3E+01	1.6E+01	1.4E+01	1.5E+01	1.4E+01
SIG.SIG.	1.3E+01	1.7E+01	1.3E+01	1.6E+01	1.4E+01	1.5E+01	1.4E+01
MTR	1.3E+01	1.7E+01	1.3E+01	1.5E+01	1.4E+01	1.5E+01	1.4E+01

ALL ENERGY VALUES IN MEV.





MTR



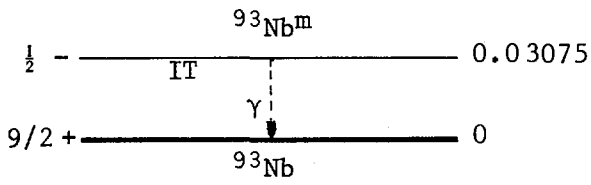
CTR

^{93}Nb (n,n') ^{93}Nb^{m}

Material constants

Relative atomic mass of element	: A_r(Nb)	= 92.9064(1)	|Ho79|,
Mass density	: ρ	= 8.57 Mg.m^{-3}	|We79|
Melting point	: T	= 2741.15 K = 2468(10)^{o}C	
Number of atoms per unit mass	: N_m	= 6.482×10^{24}kg^{-1}	
Number of atoms per unit volume	: N_v	= 55.55×10^{27}m^{-3}	
Isotopic mole fraction	: x(^{93}Nb)	= 100%	|Ho79|

Disintegration scheme



Disintegration data

^{93}Nb^{m}: half-life = 16.4(4) a * |L177|

	λ	= 1.3393×10^{-9}s^{-1}		
	IT decay	= 100%		
+	E(γ)	= 30.75(10) keV	(4.5(10))×10^{-4}%	|Ba78|
+	E (Kα)	= 16.6 keV	(11.6(4)%	
+	E (Kβ)	= 18.7 keV	$P_{K\beta}/P_{K\alpha}$ = 0.189(3)	

Activities induced in niobium

+	^{93}Nb(n,n')^{93}Nb^{m}	$T_{\frac{1}{2}}$ = 16.4 a * |L177|		<σ> = 8.7(1.4) fm^2 1)	|Er76|
	^{93}Nb(n,γ)^{94}Nb^{m}	$T_{\frac{1}{2}}$ = 6.26(1)min |MED78|		σ_0 = 15(10) fm^2	|Sh74|
	^{93}Nb(n,γ)^{94}Nbg	$T_{\frac{1}{2}}$ = 2.03(16)×10^4 a |MED78|		σ_0 = 115(5) fm^2	|Mu73|
			m+g	σ_{act} = 100(15) fm^2	|Go66|
				I = 850(50) fm^2	|Mu73|
	^{93}Nb(n,p)^{93}Zr	$T_{\frac{1}{2}}$ = 1.5×10^6a |Se74|		<σ> = 0.1 $\binom{+0.15}{-0.66}$ fm^2	|Er76|
	^{93}Nb(n,2n)^{92}Nb^{m}	$T_{\frac{1}{2}}$ = 10.15 d |Se74|		<σ> = 0.048(0.004) fm^2	|Ca74|
	^{93}Nb(n,2n)^{92}Nb	$T_{\frac{1}{2}}$ = 2×10^7 a |Er76|	m+g	<σ> = 0.11 $\binom{+0.08}{-0.04}$ fm^2	|Er76|
	^{93}Nb(n,α)^{90}Y^{m}	$T_{\frac{1}{2}}$ = 3.19 h |Se74|		<σ> = 0.00267(17) fm^2	|Ca74|
	^{93}Nb(n,α)^{90}Y	$T_{\frac{1}{2}}$ = 64.0(1) h |Ma76|		<σ> = 0.00707(51) fm^2	|Ca74|

* See remark at end

$^{94}Nb(n,\gamma)^{95}Nb^{m}$	$T_{\frac{1}{2}}$ = 86.6 h |Se74|	} σ_0 = 1360(150) fm^2	|Mu73|
$^{94}Nb(n,\gamma)^{95}Nb$	$T_{\frac{1}{2}}$ = 35.15 d |Se74|		
$^{94}Nb(n,2n)^{93}Nb$	stable	$\langle\sigma\rangle = 0.54\left(^{+0.38}_{-0.22}\right)$ fm^2	|Er76|

1) other value 9.7(3.5) fm^2 |He71|

Evaluated cross section data

620 group data : no data found

Integral data :

Differential cross section: |He77|

Remark

Values reported in literature for half-life, x-ray emission probabilities, and cross sections, show appreciable scatter. The values presented here may therefore be somewhat inconsistent.

Other results for $T_{\frac{1}{2}}$:

13.9(15) a |Ba78|

13.6 a |Wa77|.

The most recent results from continued measurements in Geel indicate an increase in the half-life value:

15.3(12) a (unpublished, April 1979).

The half-life measurements are continued both by Lloret (Grenoble) and by Bambynek (Geel). Between these two laboratories there will be an exchange of sources.

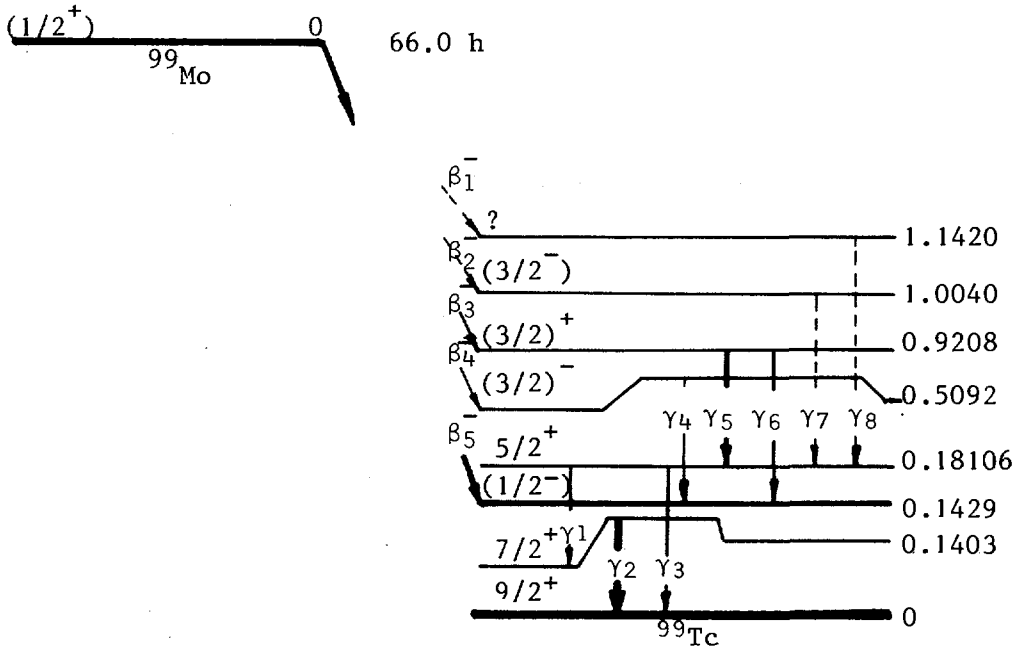
^{98}Mo (n,γ) ^{99}Mo

Material constants

Relative atomic mass of element	: A_r(Mo)	= 95.94(1)	|Ho79|,
Mass density	: ρ	= 10.22 $Mg.m^{-3}$	|We79|
Melting point	: T	= 2890.15 K = 2617 °C	
Number of atoms per unit mass	: N_m	= $6.277\times10^{24} kg^{-1}$	
Number of atoms per unit volume	: N_v	= $64.15\times10^{27} m^{-3}$	

Isotopic mole fractions	: x(^{92}Mo)	= 14.84(1) %	
+	x(^{94}Mo)	= 9.25(1) %	
	x(^{95}Mo)	= 15.92(1) %	
	x(^{96}Mo)	= 16.78(1) %	|Ho79|
+	x(^{97}Mo)	= 9.55(1) %	
+	x(^{98}Mo)	= 24.13(1) %	
	x(^{100}Mo)	= 9.63(1) %	

Disintegration scheme



Disintegration data |MED78|

+	^{99}Mo: half-life	= 66.0 (2) h		
+	λ	= $2.9173\times10^{-6} s^{-1}$		
+	E(β_1^-) max	214.9(10) keV		
+	av	59.9(3) keV	(0.111(3)%)	
+	E(β_2^-) max	352.7(10) keV		
+	av	104.3(4) keV	(0.134(4)%)	

$E(\beta_3^-)$ max 436.1(10) keV
av 133.0(4) keV (16.55(7)%)
$E(\beta_4^-)$ max 847.6(10) keV
av 289.6(4) keV (1.17(3)%)
$E(\beta_5^-)$ max 1214.1(10) keV
442.7(5) keV (81.96(18)%)
Total β^- av 388.7(6) keV (99.94(20)%)
2 weak β's omitted ($\Sigma P\beta$ = 0.01%)

+ $E(\gamma_1)$ 40.587(15) keV (1.15(4)%)
+ $E(\gamma_2)$ 140.466(15) keV (4.95(9)%)
+ $E(\gamma_3)$ 181.057(15) keV (6.06(8)%)
+ $E(\gamma_4)$ 366.421(15) keV (1.193(24)%)
+ $E(\gamma_5)$ 739.500(15) keV (12.194(17)%)
+ $E(\gamma_6)$ 777.921(20) keV (4.32(7)%)
+ $E(\gamma_7)$ 822.972(15) keV (0.133(4)%)
+ $E(\gamma_8)$ 960.69(3) keV (0.101(5)%)
+ 25 weak γ's omitted ($\Sigma P\gamma$ = 0.27%)

^{99}Tcm: feeding of $^{99}Tc^m$ in ^{99}Mo decay = 87.52(18)%
half-life = 6.02(3) h
λ = $31.984\times10^{-6}s^{-1}$
$E(\gamma_2)$ = 140.466(15)keV (88.97(24)%)
2 weak γ's omitted ($\Sigma P\gamma$ = 0.02%)

γ-rays emitted per decay of ^{99}Mo in case of radioactive equilibrium of ^{99}Mo and $^{99}Tc^m$: γ_1, γ_3-γ_7 see ^{99}Mo
$E(\gamma_2)$ 140.466(15) keV (90.6(4)%)

<u>Activities induced in molybdenium</u>

$^{98}Mo(n,\gamma)^{99}Mo$
$T_{\frac{1}{2}}$ = 66.0 h |MED78| σ_{act} = 13.0(6) fm^2 |Mu73|
I = 620(30) fm^2 |Mu73|
g value Westcott convention 1.0
s_0 value Westcott convention 55.90(311) (for σ_0=15(2) fm^2) |Ki73|

$^{100}Mo(n,\gamma)^{101}Mo$	$T_{\frac{1}{2}}$ = 14.6 min	|Se74|	σ_{act} = 19.9(3) fm^2	|Mu73|
$^{97}Mo(n,\gamma)^{98}Mo$	stable		σ_{act} = 220(70) fm^2	
$^{92}Mo(n,\gamma)^{93}Mo^m$	$T_{\frac{1}{2}}$ = 6.9 h	|Se74|	σ_{act} = <0.6 fm^2	
$^{92}Mo(n,\gamma)^{93}Mo$	$T_{\frac{1}{2}}$ = 3.5×10^3 a	|Se74|	σ_{act} = ~4.5 fm^2	
$^{92}Mo(n,p)^{92}Nb^m$	$T_{\frac{1}{2}}$ = 10.15 d	|Se74|	$\langle\sigma\rangle$ = 0.70(6) fm^2	|Ca74|
$^{95}Mo(n,p)^{95}Nb$	$T_{\frac{1}{2}}$ = 35.15 d		$\langle\sigma\rangle$ = 0.014(1) fm^2	
$^{96}Mo(n,p)^{96}Nb$	$T_{\frac{1}{2}}$ = 23.4 h		$\langle\sigma\rangle$ = 0.023(3) fm^2	
$^{92}Mo(n,\alpha)^{89}Zr$	$T_{\frac{1}{2}}$ = 78.4 h		$\langle\sigma\rangle$ = 0.004(2) fm^2	

Evaluated cross section data

620 group data : -

Integral data : -

Remark:

^{99}Mo is usually measured in radioactive equilibrium with $^{99}Tc^m$.

P_{γ_2} is now $0.8752 \times \frac{66.0}{66.0-6.02} \times 88.97 + 4.95 = 90.6\%$.

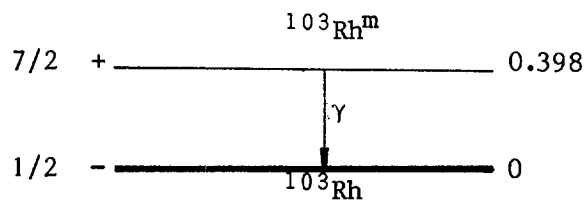
When equilibrium has not been reached, one should take into account the build-up of $^{99}Tc^m$ (see preface).

$^{103}Rh\ (n,n')\ ^{103}Rh^m$

Material constants

Relative atomic mass of element	: $A_r(Rh)$	= 102.9055(1)	|Ho79|,
Mass density	: ρ	= 12.41 $Mg.m^{-3}$	|We79|
Melting point	: T	= 2239.15 K = 1966(3) °C	
Number of atoms per unit mass	: N_m	= $5.852\times10^{24}kg^{-1}$	
Number of atoms per unit volume	: N_v	= $72.63\times10^{27}m^{-3}$	
Isotopic mole fraction	: $x(^{103}Rh)$	= 100%	|Ho79|

Disintegration scheme



Disintegration data |MED78|

$^{103}Rh^m$: half-life = 56.12(1) min

	λ	= $0.20585\times10^{-3}s^{-1}$	
+	E_γ	= 39.8 keV	(0.07%)
	Auger-L	2.39 keV	(76.6(15)%)
	Ce-K-1	16.530(7) keV	(9.5(3)%)
	Auger-K	17 keV	(1.8(3)%)
	Ce-L-1	36.338(7) keV	(71.290(10%)
	Ce-M-1	39.123(7) keV	(14.4(4)%)
	Ce-NOP-1	39.669(7) keV	(4.70(20)%)
X-rays	L	2.7 keV	(4.0(13)%)
	K_{α_2}	20.07370(2) keV	(2.19(12)%)*
	K_{α_1}	20.21610(2) keV	(4.17(21)%)*
	K_β	22.7 keV	(1.30(7)%) *

* ΣPKx = (2.19 + 4.17 + 1.30)% = 7.66%.

ΣPKX measurements at CBNM, Geel, result in a higher value 8.4(5)%.

Measurements at SCK/CEN, Mol, confirm the results of CBNM.

Activities induced in rhodium

$^{103}Rh(n,n')^{103}Rh^m$	$T_{\frac{1}{2}}$ = 56.12(1) min	|MED78|	$\langle\sigma\rangle$ = 73.3(38) fm^2	|Fa77|
$^{103}Rh(n,\gamma)^{104}Rh^g$	$T_{\frac{1}{2}}$ = 42 s |Se74|		σ_o = 13900(700) fm^2	|Mu73|
$^{103}Rh(n,\gamma)^{104}Rh^m$	$T_{\frac{1}{2}}$ = 4.4 min |Se74|		σ_o = 1100(100) fm^2	|Mu73|
$^{104}Rh^{g+m}$			σ_o = 15000(500) fm^2	|Mu73|
			I = $110(5)\times10^3$ fm^2	|Mu73|
$^{103}Rh(n,2n)^{102}Rh^m$	$T_{\frac{1}{2}}$ = 2.9 a	|Se74|	$\langle\sigma\rangle$ = 0.065 fm^2	|Pu76|
$^{103}Rh(n,2n)^{102}Rh^g$	$T_{\frac{1}{2}}$ = 206 d	|Se74|	$\langle\sigma\rangle$ = 0.010 fm^2	|Pu76|
$^{102}Rh^{m+g}$			$\langle\sigma\rangle$ = $0.0740\binom{+500}{-300}$ fm^2	|Er76|
$^{103}Rh(n,p)^{103}Ru$	$T_{\frac{1}{2}}$ = 39.35 d	|Se74|	$\langle\sigma\rangle$ = 0.0107(6) fm^2	|Ca74|

Evaluated cross section data

620 group data : |La75|, |Zij77|

Integral data : $\langle\sigma\rangle$ = 72.4(43) fm^2 |Sa74|

(for a Watt representation): $\langle\sigma\rangle_c$ = 713.5 mb = 71.35 fm^2 |Zij77|

Differential cross section : |Sa74|

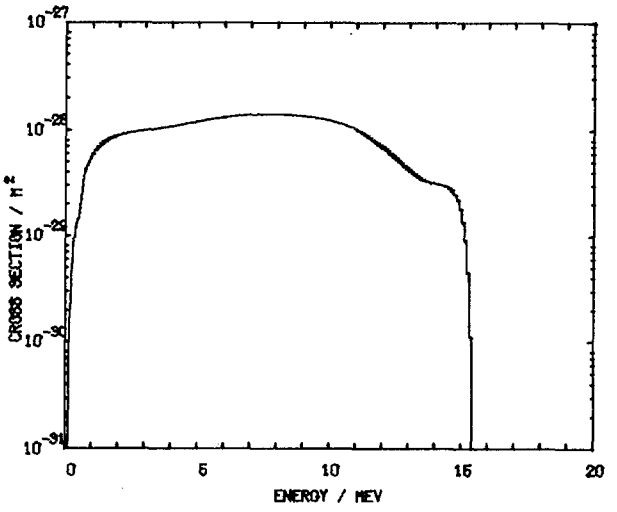
Response data

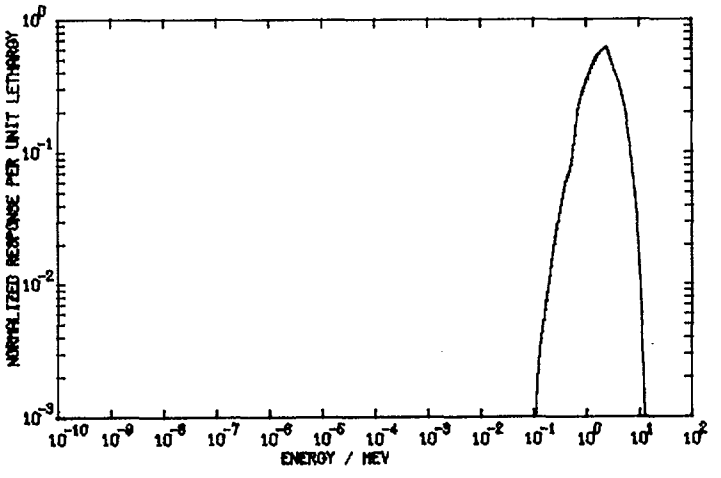
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: 103RH(N,N)103RHM

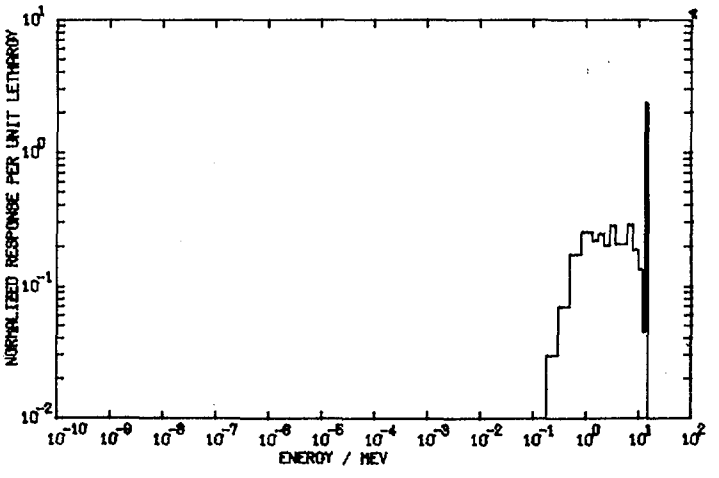
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	3.0E-01	1.4E+01	8.2E-01	1.4E+01	1.7E+00	6.1E+00	2.9E+00
252CF	7.6E-01	6.4E+00	1.3E+00	4.1E+00	1.8E+00	3.1E+00	2.4E+00
235U	7.2E-01	6.0E+00	1.2E+00	3.8E+00	1.7E+00	2.9E+00	2.2E+00
CFRMF	3.6E-01	5.2E+00	6.9E-01	2.9E+00	1.0E+00	1.9E+00	1.4E+00
SIG.SIG.	3.6E-01	5.0E+00	7.2E-01	2.8E+00	1.0E+00	1.9E+00	1.4E+00
MTR	5.5E-01	5.6E+00	1.0E+00	3.4E+00	1.5E+00	2.5E+00	1.9E+00

ALL ENERGY VALUES IN MEV.





MTR



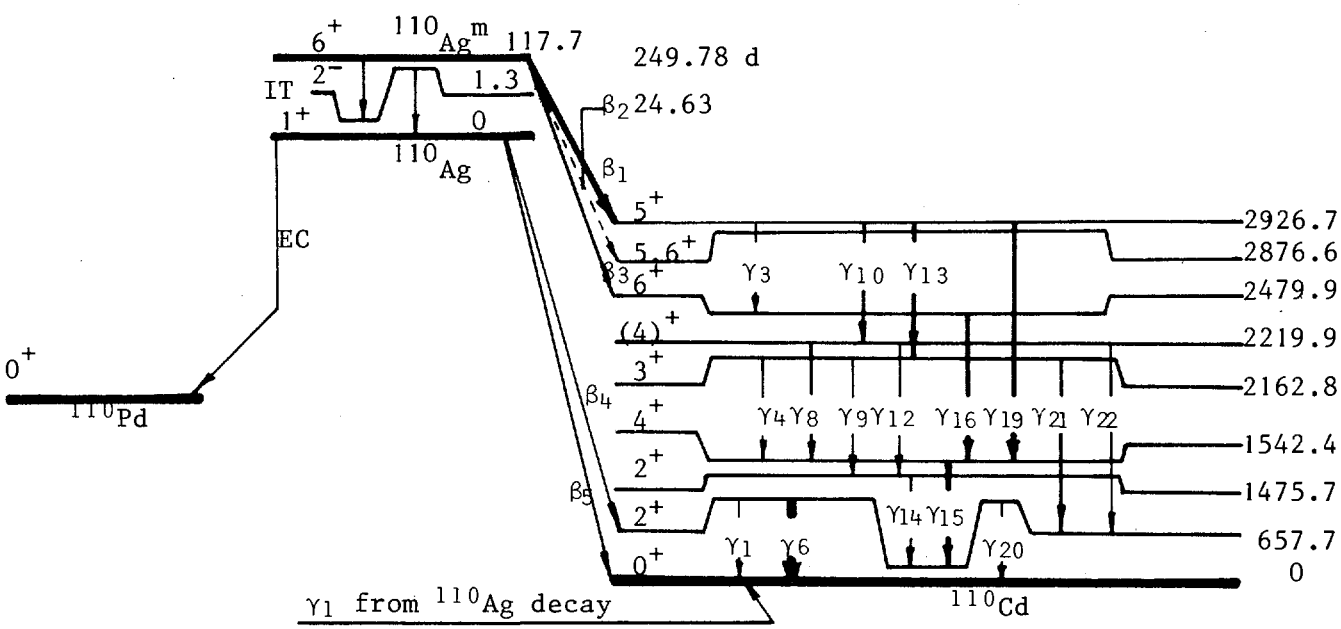
CTR

$^{109}Ag(n,\gamma)^{110}Ag^{m}$

Material constants

Relative atomic mass of element	: $A_r(Ag)$	= 107.868(1)	|Ho79|
Mass density	: ρ	= 10.50 $Mg.m^{-3}$	|We79|
Melting point	: T	= 1235.08 K = 961.93 °C	|We79|
Number of atoms per unit mass	: N_m	= $5.583\times10^{24} kg^{-1}$	
Number of atoms per unit volume	: N_v	= $58.62\times10^{27} m^{-3}$	
Isotopic mole fractions	: $x(^{107}Ag)$	= 51.83(3) %	|Ho79|
	$x(^{109}Ag)$	= 48.17(3) %	

Disintegration scheme



Disintegration data |MED78|

+ $^{110}Ag^{m}$: half-life = 249.78(4) d |PTB79|

+ λ = $32.1184\times10^{-9} s^{-1}$

IT decay 1.33(10)%

β^- decay

+ $E(\beta_1^-)$ max 83.9(19) keV

av 21.5(6) keV (67.5(9)%)

+ $E(\beta_2^-)$ max 133.8(19) keV

av 35.3(6) keV (0.408(12)%)

+ $E(\beta_3^-)$ max 530.7(19) keV

+ av 165.1(7) keV (30.6(4)%)

+ Total β^- av 66.2(14) keV (98.7(10)%)

4 weak β's omitted ($\Sigma P\beta$ = 0.18%)

	$E(\gamma_2)$	365.441(15) keV	(0.106(9)%)
+	$E(\gamma_3)$	446.797(8) keV	(3.66(4)%)
+	$E(\gamma_4)$	620.346(11) keV	(2.78(3)%)
	$E(\gamma_5)$	626.246(10) keV	(0.235(7)%)
+	$E(\gamma_6)$	657.749(10) keV	(94.70(10)%) *
	$E(\gamma_7)$	676.60(10) keV	(0.142(19)%)
+	$E(\gamma_8)$	677.606(11) keV	(10.72(11)%)
+	$E(\gamma_9)$	686.988(11) keV	(6.49(7)%)
+	$E(\gamma_{10})$	706.670(13) keV	(16.74(12)%)
	$E(\gamma_{11})$	708.115(20) keV	(0.28(10)%)
+	$E(\gamma_{12})$	744.260(13) keV	(4.66(55)%)
+	$E(\gamma_{13})$	763.928(13) keV	(22.36(23)%)
+	$E(\gamma_{14})$	818.016(12) keV	(7.32(8)%)
+	$E(\gamma_{15})$	884.667(13) keV	(72.9(8)%)
+	$E(\gamma_{16})$	937.478(13) keV	(34.3(4)%)
	$E(\gamma_{17})$	997.233(18) keV	(0.125(5)%)
	$E(\gamma_{18})$	1334.304(17) keV	(0.133(10)%)
+	$E(\gamma_{19})$	1384.270(13) keV	(24.35(25)%)
+	$E(\gamma_{20})$	1475.759(22) keV	(3.99(4)%)
+	$E(\gamma_{21})$	1505.001(21) keV	(13.11(14)%)
+	$E(\gamma_{22})$	1562.266(22) keV	(1.184(13)%)

40 weak γ's omitted ($\Sigma P\gamma$ = 0.92%)

^{110}Ag: half-life = 24.6(2) s

λ = $28.177\times10^{-3}s^{-1}$

EC decay = 0.30(6)%

β^- decay

$E(\beta_4^-)$ max 2235.0(19) keV

av 894.1(9) keV (4.4(3)%)

$E(\beta_5^-)$ max 2892.8(19) keV

av 1199.3(9) keV (95.2(3)%)

Total β^- av 1185.1(9) keV (99.7(5)%)

9 weak β's omitted ($\Sigma P\beta$ = 0.09%)

$E(\gamma_1)$ 657.749(10) keV (4.50(23)%)

12 weak γ's omitted ($\Sigma P\gamma$ = 0.10%)

*Remark: It is believed that the value 94.7(10)% |MED78| is not correct.

Activities induced in silver

	$^{107}Ag(n,\gamma)^{108}Ag^{m}$	$T_{\frac{1}{2}}$ = 127(21)a	|MED78|	σ_{act} = 300(150) fm^2	|Mu73| $^{108}Ag^{g+m}$
+	$^{107}Ag(n,\gamma)^{108}Ag$	$T_{\frac{1}{2}}$ = 2.37(1)min	|MED78|	σ_{act} = 3720(120) fm^2	
+	$^{109}Ag(n,\gamma)^{110}Ag^{m}$	$T_{\frac{1}{2}}$ = 249.78 d	|PTB79|	σ_{act} = 498(47) fm^2	|Si68|
	$^{109}Ag(n,\gamma)^{110}Ag$	$T_{\frac{1}{2}}$ = 24.6 s	|MED78|	σ_{act} = 8900(400) fm^2 ($^{110}Ag^{g}$)	|Mu73|
				σ_{act} = 9100(300) fm^2 ($^{110}Ag^{g+m}$)	
	$^{110}Ag^{m}(n,\gamma)^{111}Ag$	$T_{\frac{1}{2}}$ = 7.45(1)	|MED78|	σ_{act} = 8200(1100) fm^2	

$^{109}Ag(n,\gamma)^{110}Ag^{m}$

I = 8110(220) fm^2 |Si68| I' = 7770(210) fm^2 |Si68|

g value Westcott convention 1.000

s_0 value Westcott convention 17.61

Evaluated cross section data

620 group data : |Ei74|, |Zij77|

Integral data : $g.\sigma_0$ = 415.2 fm^2 |Zij77|

I = 6552 fm^2

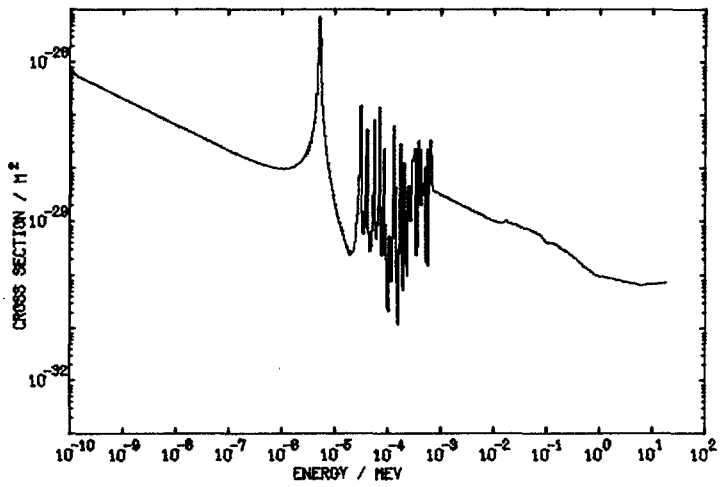
Response data

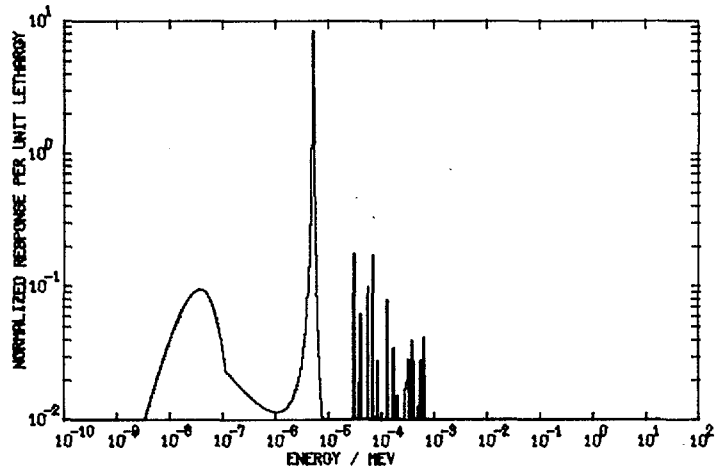
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: AG109(N,G)AG110M

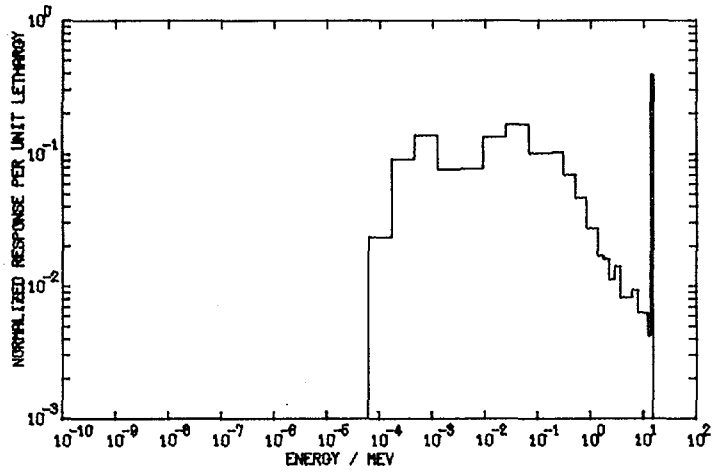
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.7E-04	3.7E+00	4.5E-04	6.8E-02	3.4E-03	2.5E-02	9.1E-03
252CF	7.6E-02	4.7E+00	2.8E-01	2.5E+00	5.8E-01	1.6E+00	1.0E+00
235U	6.6E-02	4.3E+00	2.6E-01	2.3E+00	5.0E-01	1.5E+00	9.2E-01
CFRMF	2.8E-04	9.2E-01	1.2E-03	2.8E-01	1.3E-02	1.3E-01	5.3E-02
SIG.SIG.	6.9E-05	1.0E+00	2.3E-03	3.2E-01	2.3E-02	1.5E-01	6.6E-02
MTR	1.5E-08	4.0E-05	1.3E-07	5.3E-06	5.0E-06	5.0E-06	5.0E-06

ALL ENERGY VALUES IN MEV.





MTR



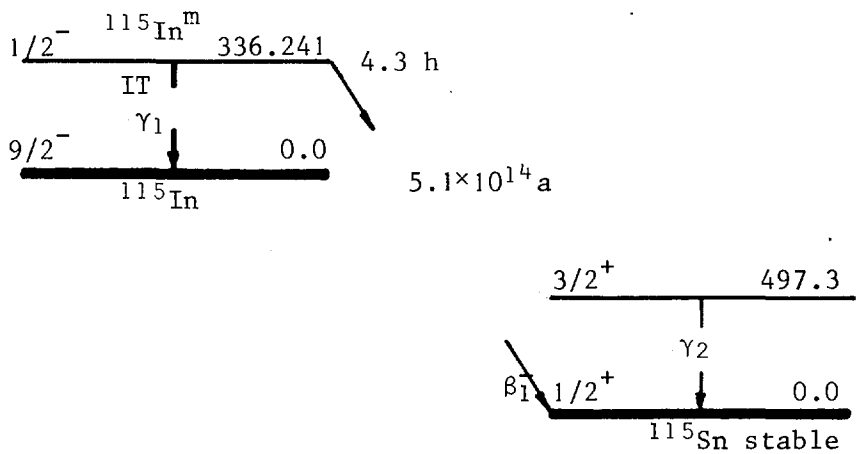
CTR

$^{115}In(n,n')^{115}In^{m}$

Material constants

See reaction $^{115}In(n,\gamma)^{116}In^{m}$

Disintegration scheme |Ra75|



Disintegration data |MED78|

$^{115}In^{m}$: half-life = 4.486(4) h |Ha74|

λ = $42.920 \times 10^{-6} s^{-1}$

IT decay = 96.3(8)%

\+ $E(\gamma_1)$ = 336.241(25) keV 46.7(6)% *

β^- decay = 3.7(8)%

\+ $E(\beta_1^-)$ max 859(9) keV

av 290(3) keV 3.7(8)%

\+ 1 weak β's omitted ($\Sigma P\beta$ = 0.04%)

* See remarks at the end.

+ ^{115}In: half-life = $(5.1(4))\times10^{14}$a |MED78|

^{115}Sn: $E(\gamma_2)$ 497.3(5) keV $P_{\gamma2}/P_{\gamma1}$ $(1.03(2))\times10^{-3}$ |Ha74|

Activities induced in indium

+ $^{115}In(n,n')^{115}In^m$ $T_{\frac{1}{2}}$ =4.486(4) h |Ha74| $\langle\sigma\rangle$ = 18.9(8) fm^2 |Fa77|

see for other reactions the reaction $^{115}In(n,\gamma)^{116}In^m$

Remarks: $^{115}In^m$ to be counted after decay of $^{113}In^m$
$T_{\frac{1}{2}}$ = 99.4 min; E_γ = 392 keV (64%)

Evaluated cross section data

+ 620 group data : |Sm76|, |Zij77|
Integral data : for a ^{235}U fission spectrum:
(for a Watt representation): $\langle\sigma\rangle$ = 0.1768 b = 17.68 fm^2 |Zij77|
most recent evaluation: $\langle\sigma\rangle^f$=17.28 fm^2 |Sm76|

Remark

Experimental activity values and derived cross section values depend often on the γ-ray emission probability of the 336.241 keV gamma radiation. In some publications (and also in the ENDF/B-IV dosimetry file) a value of 50% is used.

For the γ-ray emission probability of the 336.241 keV gamma radiation the following values have been reported : 50 % |ENDF/B-IV dosimetry file|
45.9(1) % |Ha74|
46.7(6) % |Ma76|, |MED78|
46.7(7) % |Ko77|

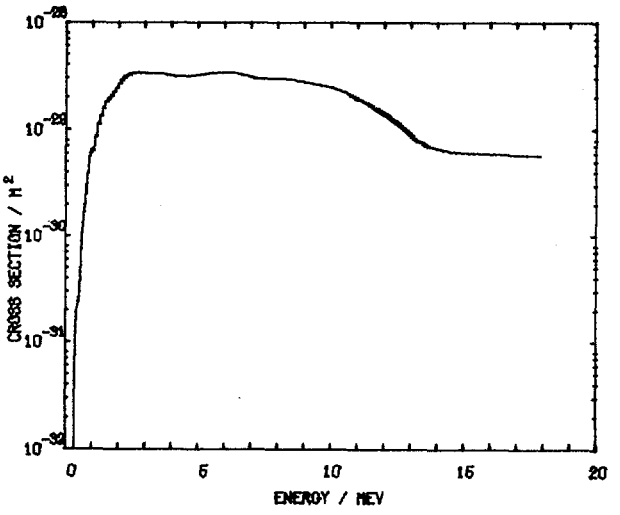
Response data

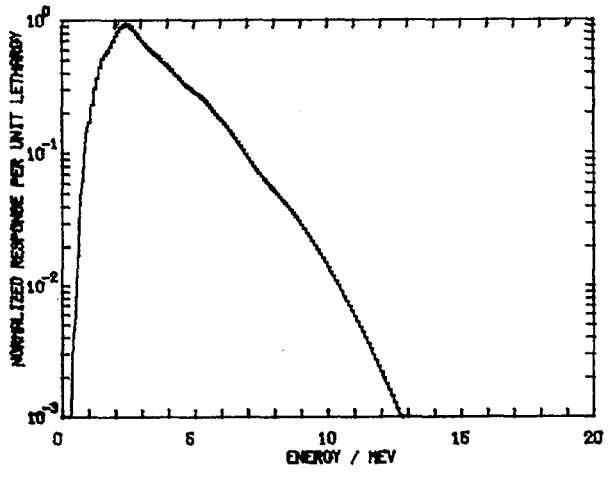
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: IN115(N,N)IN115M

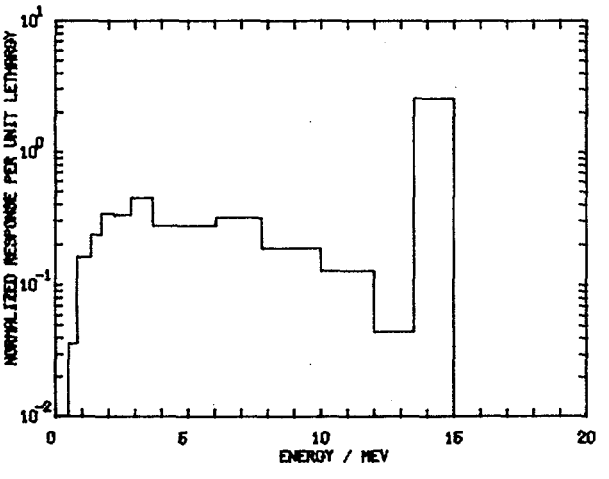
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	8.2E-01	1.4E+01	1.7E+00	1.4E+01	2.9E+00	6.1E+00	3.7E+00
252CF	1.1E+00	6.2E+00	1.7E+00	4.1E+00	2.2E+00	3.2E+00	2.7E+00
235U	1.1E+00	5.9E+00	1.7E+00	3.9E+00	2.1E+00	3.1E+00	2.6E+00
CFRMF	8.4E-01	5.6E+00	1.3E+00	3.5E+00	1.8E+00	2.7E+00	2.2E+00
SIG.SIG.	8.4E-01	5.4E+00	1.3E+00	3.4E+00	1.8E+00	2.7E+00	2.2E+00
MTR	1.0E+00	5.6E+00	1.6E+00	3.7E+00	2.0E+00	2.9E+00	2.4E+00

ALL ENERGY VALUES IN MEV.





MTR



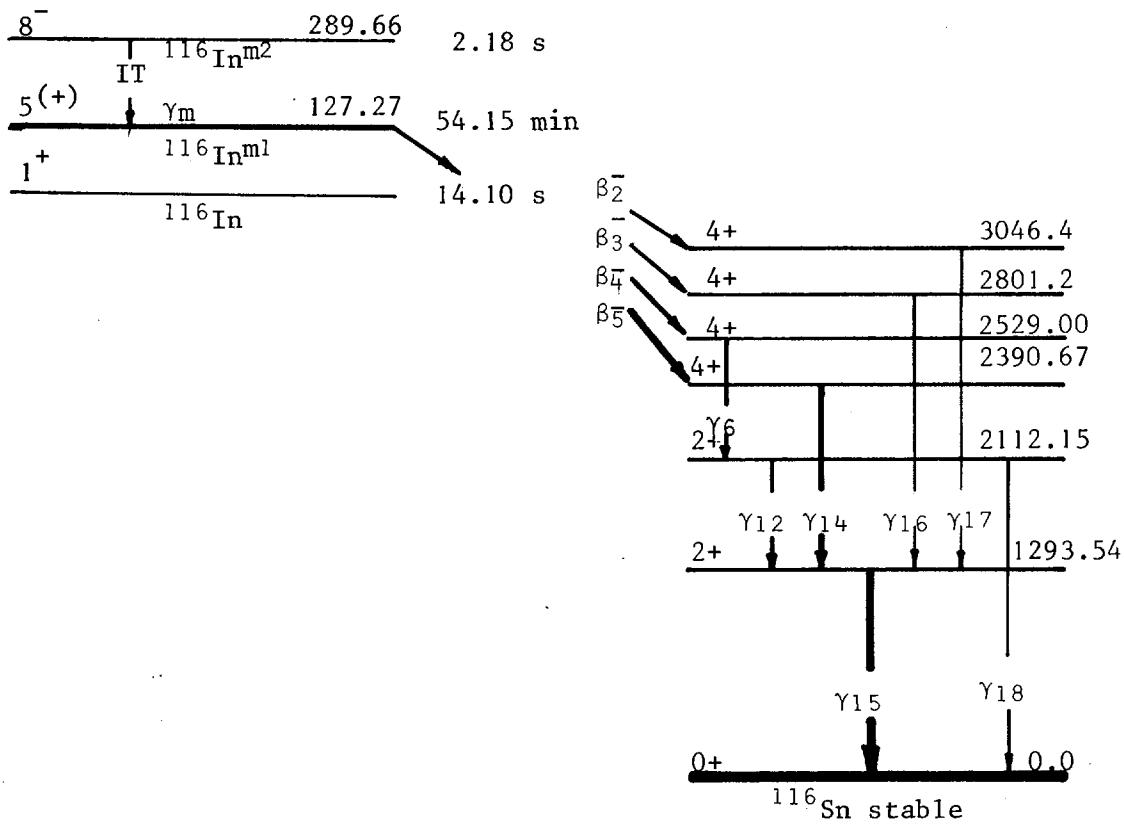
CTR

$^{115}In(n,\gamma)^{116}In^{m}$

Material constants

Relative atomic mass of element:	$A_r(In)$	= 114.82(1)	|Ho79|,
Mass density	: ρ	= 7.31 $Mg.m^{-3}$	|We79|
Melting point	: T	= 429.76 K = 156.61 °C	
Number of atoms per unit mass	: N_m	= $5.245\times10^{24}kg^{-1}$	
Number of atoms per unit volume:	N_v	= $38.34\times10^{27}m^{-3}$	
Isotopic mole fractions	: $x(^{113}In)$	= 4.3(1) %	|Ho79|
	$x(^{115}In)$	= 95.7(1) %	

Disintegration scheme |Ca75|



Disintegration data |MED78|

$^{116}In^{m}_{2}$: half-life : $T_{\frac{1}{2}}$ = 2.18(4) s |Ca75|

decay constant: λ = $3.1796\times10^{-1}s^{-1}$

IT decay

$E(\gamma_{20})$ = 162.39(2) keV |Ca75|

$^{116}In^{m}{}_{1}$: half-life = 54.15(6) min

λ = $0.21334\times10^{-3}s^{-1}$

β^- decay

+	$E(\beta_1^-)$	max	302(8) keV	
		av	87(3) keV	(0.33(4)%)
+	$E(\beta_2^-)$	max	352(8) keV	
		av	103(3) keV	(2.71(10)%)
+	$E(\beta_3^-)$	max	597(8) keV	
		av	189(3) keV	(10.2(4)%)
+	$E(\beta_4^-)$	max	869(8) keV	
		av	294(4) keV	(33.6(15)%)
+	$E(\beta_5^-)$	max	1007(8) keV	
		av	351(4) keV	(51.8(11)%)
	Total	av	307(4) keV	(98.6(19)%)

	$E(\gamma_1)$	138.326(8) keV	(3.29(12)%)
	$E(\gamma_2)$	262.95(8) keV	(0.12(3)%)
	$E(\gamma_3)$	278.49(8) keV	(0.143(17)%)
	$E(\gamma_4)$	303.80(7) keV	(0.118(17)%)
	$E(\gamma_5)$	355.36(4) keV	(0.83(5)%)
	$E(\gamma_6)$	416.86(3) keV	(29.2(15)%)
	$E(\gamma_7)$	463.14(12) keV	(0.83(5)%)
	$E(\gamma_8)$	655.7(4) keV	(0.11(5)%)
	$E(\gamma_9)$	689.0(3) keV	(0.16(3)%)
	$E(\gamma_{10})$	705.7(3) keV	(0.17(3)%)
	$E(\gamma_{11})$	781.1(8) keV	(0.110(21)%)
	$E(\gamma_{12})$	818.70(20) keV	(11.5(5)%)
	$E(\gamma_{13})$	972.55(3) keV	(0.454(17)%)
	$E(\gamma_{14})$	1097.30(20) keV	(56.2(12)%)
	$E(\gamma_{15})$	1293.54(4) keV	(84.4(18)%)
	$E(\gamma_{16})$	1507.40(20) keV	(10.0(4)%)
	$E(\gamma_{17})$	1753.8(6) keV	(2.46(8)%)
	$E(\gamma_{18})$	2112.1(4) keV	(15.5(5)%)

25 weak γ's omitted (ΣP_γ = 1.02%)

+ ^{116}In : half-life = 14.10(3) s

λ = $49.159\times10^{-3}s^{-1}$

For the ^{116}In the decay energies and emission probabilities for β- and gamma transitions are not included in this guide, since for radiation metrology purposes only the decay of $^{116}In^{m1}$ with half-life of 54.15 min is of interest.

Activities induced in indium

	$^{113}In(n,\gamma)^{114}In^{m2}$	$T_{\frac{1}{2}}$ = 42 ms |Se74|	σ = 310(70) fm^2	
	$^{113}In(n,\gamma)^{114}In^{m1}$	$T_{\frac{1}{2}}$ = 49.5 d |Se74|	σ = 440(70) fm^2	
	$^{113}In(n,\gamma)^{114}In$	$T_{\frac{1}{2}}$ = 71.9 s |Se74|	σ = 390(40) fm^2	
	Total		σ = 1140(110) fm^2	
			I = 28200(3000) fm^2	
+	$^{115}In(n,\gamma)^{116}In^{m2}$	$T_{\frac{1}{2}}$ = 2.18 s |Ca75|	σ = 9200(1400) fm^2	|Mu73|
	$^{115}In(n,\gamma)^{116}In^{m1}$	$T_{\frac{1}{2}}$ = 54.15 min |MED78|	σ = 6500(500) fm^2	
			σ = 15700(1500) fm^2	(m_1+m_2)
+	$^{115}In(n,\gamma)^{116}In$	$T_{\frac{1}{2}}$ = 14.1s |MED78|	σ = 4500(400) fm^2	
	Total		σ = 20200(200) fm^2	
			I = 330000(10000) fm^2	

g value Westcott convention 1.03

+	$^{115}In(n,n')^{115}In^{m}$	* $T_{\frac{1}{2}}$ = 4.3(1) h |MED78|	<σ> = 18.9(8) fm^2	|Fa76|
	$^{115}In(n,p)^{115}Cd$	$T_{\frac{1}{2}}$ = 53.38 h → β^- $^{115}In^{m}$ |Se74|	<σ> = 0.01 fm^2	|Ro60|
		estimated	<σ> = 0.0041 fm^2	|Ca74|

Evaluated cross section data

620 group data : \|Ma75\|, \|Zij77\|

Integral data : $g.\sigma_0$ = 15920 fm^2 \|Zij77\|

I = 323000 fm^2

* See remark at the reaction $^{115}In(n,n')^{115}In^{m}$

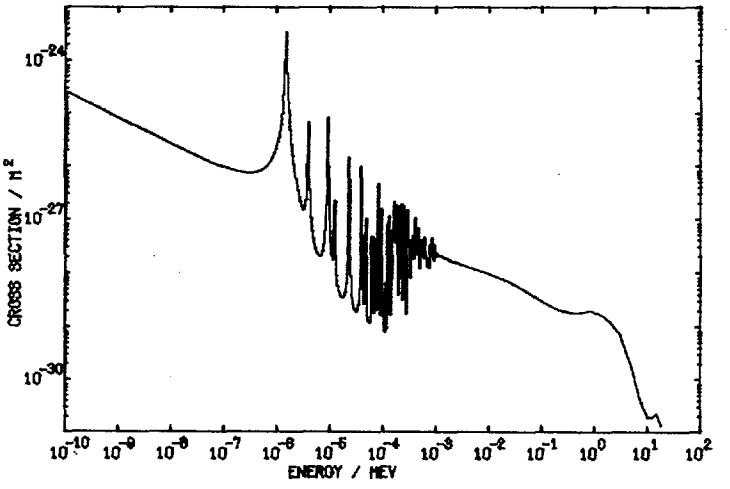
Response data

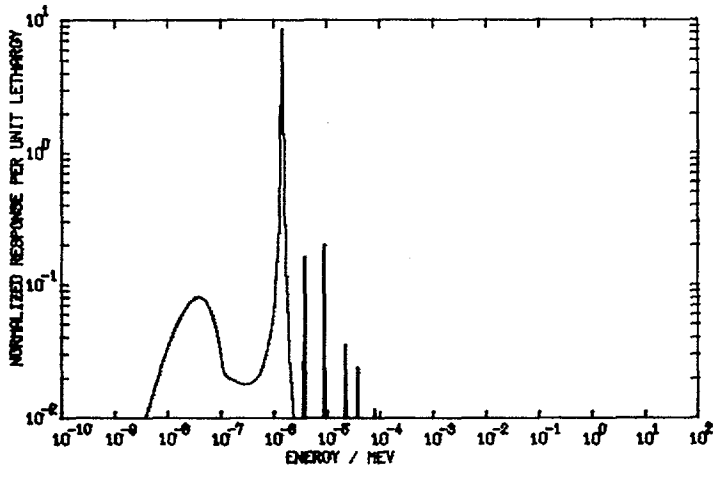
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: IN115(N,G)IN116M

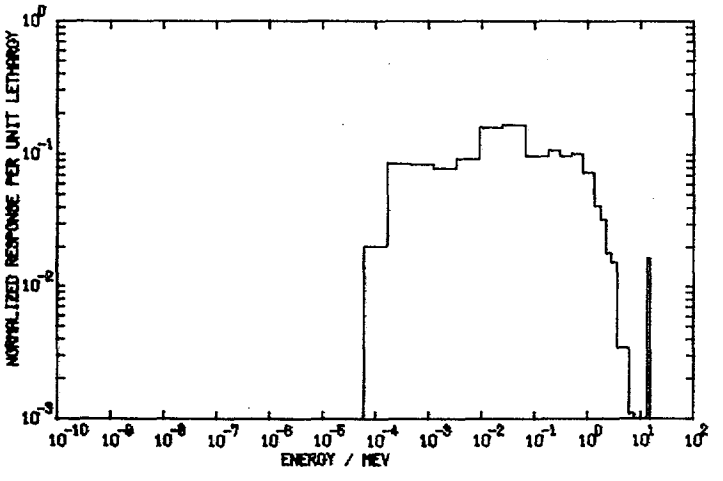
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.7E-04	8.2E-01	1.2E-03	1.8E-01	3.4E-03	2.5E-02	9.1E-03
252CF	1.2E-01	3.1E+00	4.5E-01	1.9E+00	7.6E-01	1.4E+00	1.0E+00
235U	1.1E-01	3.0E+00	4.3E-01	1.8E+00	7.2E-01	1.3E+00	1.0E+00
CFRMF	2.4E-04	1.3E+00	3.4E-03	5.0E-01	2.7E-02	2.3E-01	8.8E-02
SIG.SIG.	2.2E-04	1.4E+00	9.2E-03	6.0E-01	4.0E-02	2.8E-01	1.2E-01
MTR	1.7E-08	1.6E-06	5.5E-07	1.4E-06	1.4E-06	1.4E-06	1.4E-06

ALL ENERGY VALUES IN MEV.





MTR



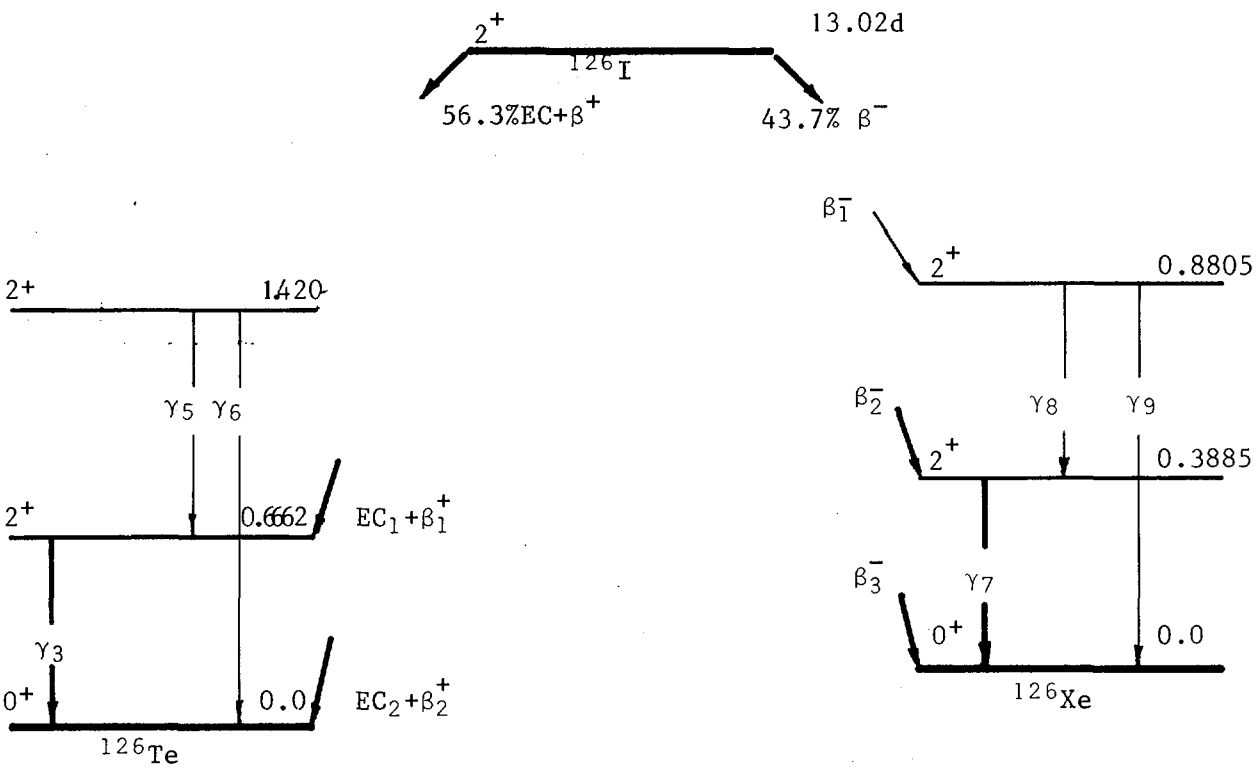
CTR

$^{127}I\,(n,2n)\,^{126}I$

Material constants

Relative atomic mass of element	: $A_r(I)$	= 126.9045(1)	|Ho79|
Mass density	: ρ	= 4.93 $Mg.m^{-3}$	|We79|
Melting point	: T	= 386.65 K = 113.5°C	|We79|
Number of atoms per unit mass	: N_m	= $4.746\times10^{24}kg^{-1}$	
Number of atoms per unit volume	: N_v	= $23.40\times10^{27}m^{-3}$	
Isotopic mole fractions	: $x(^{127}I)$	= 100%	|Ho79|

Disintegration scheme |Au73|



Disintegration data |MED78|

^{126}I half-life : $T_{\frac{1}{2}}$ = 13.02(7) d

decay constant : λ = $6.16170\times10^{-7}s^{-1}$

Percentage feeding to ^{126}Te: 56.3(20)% EC+β^+ decay.

$E(\beta_1^+)$ max = 1134(5) keV; av = 508.4(23) keV; 3.34(22)%.

$E(\gamma_3)$	666.331(12) keV	(33.1(25)%)
$E(\gamma_5)$	753.819(13) keV	(4.2(4)%)
$E(\gamma_6)$	1420.19 (3) keV	(0.295(23)%)
$E(\gamma^{\pm})$	511.0034(14)keV	maximum (6.68%)

Percentage feeding to ^{126}Xe: 43.7(20)% β^- decay

$E(\beta_1^-)$max	371(5) keV;	av 108.9(17) keV	(3.6(3)%)
$E(\beta_2^-)$max	862(5) keV;	av 289.7(20) keV	(32 (3)%)
$E(\beta_3^-)$max	1251(5) keV;	av 449.5(22) keV	(8 (3)%)
total β^-		av 304.1(22) keV	(44 (5)%)
$E(\gamma_7)$	388.633(11)		(34 (3)%)
$E(\gamma_8)$	491.243(11)		(2.85(22)%)
$E(\gamma_9)$	879.876(13)		(0.75(6)%)

<u>Activities induced in iodine</u>

$^{127}I(n,\gamma)^{128}I$	; $T_{\frac{1}{2}}$ = 25.00 min	|Wa77|	; σ_0 = 6.2(2)b=620 fm^2 |Mu73|
			I = 147(6)b=14700 fm^2 |Mu73|
$^{127}I(n,p)^{127}Te^m$	; $T_{\frac{1}{2}}$ = 109 d	|Wa77|	;$\langle\sigma\rangle$ = 0.0128(8)mb=0.00128 fm^2 |Ca74|
$^{127}I(n,p)^{127}Te$	; $T_{\frac{1}{2}}$ = 9.4 h	|Wa77|	;$\langle\sigma\rangle$ = 0.0088(5)mb=0.00088 fm^2 |Ca74|
$^{127}I(n,2n)^{126}I$	; $T_{\frac{1}{2}}$ = 13.02 d	|MED78|	;$\langle\sigma\rangle$ = 0.9(1) mb = 0.09 fm^2 |Ca74|
$^{126}I(n,\gamma)^{127}I$	; stable		; σ_0 = 5960 b = 596000 fm^2 } |Mu73|
			I = 40600b = 4060000 fm^2 }

Evaluated cross section data :

620 group data : |Ma75| , |Zij77|

Integral data : for a ^{235}U fission spectrum :

(for a Watt representation): $\langle\sigma\rangle_c$ = 1.149 mb = 0.1149 fm^2 |Zij77|

$\langle\sigma\rangle_c$ = 1.368 mb = 0.1368 fm^2 |Ma75,2|

$\langle\sigma\rangle_m$ = 1.050(65)mb = 0.105 fm^2 |Fa78|

Response data

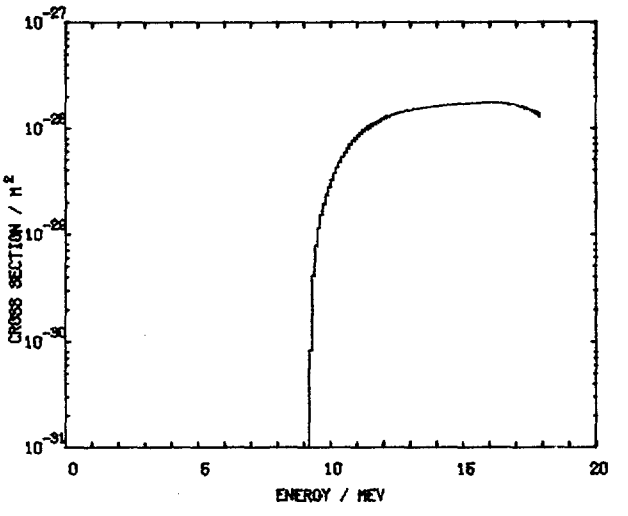
Threshold energy : E_T = 10.5 MeV |Fa78|

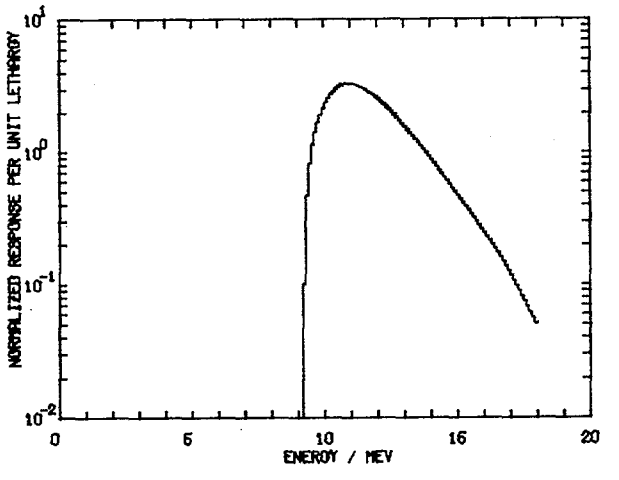
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: I127(N,2N)I126

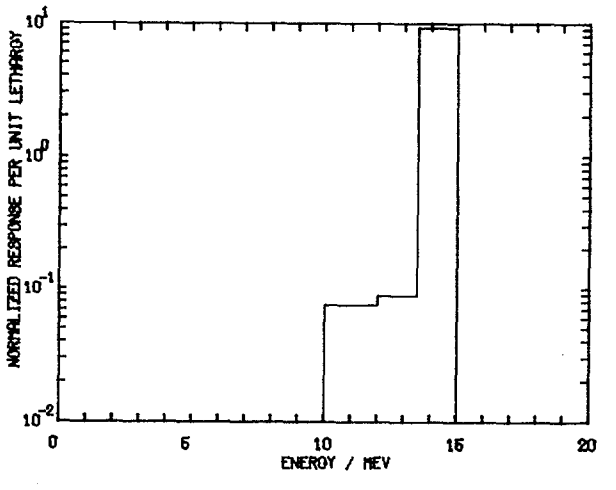
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	9.7E+00	1.5E+01	1.0E+01	1.3E+01	1.1E+01	1.2E+01	1.1E+01
235U	9.7E+00	1.4E+01	1.0E+01	1.3E+01	1.1E+01	1.2E+01	1.1E+01
CFRMF	9.7E+00	1.5E+01	1.0E+01	1.3E+01	1.1E+01	1.2E+01	1.1E+01
SIG.SIG.	9.7E+00	1.5E+01	1.0E+01	1.3E+01	1.1E+01	1.2E+01	1.1E+01
MTR	9.7E+00	1.5E+01	1.0E+01	1.3E+01	1.1E+01	1.2E+01	1.1E+01

ALL ENERGY VALUES IN MEV.





MTR



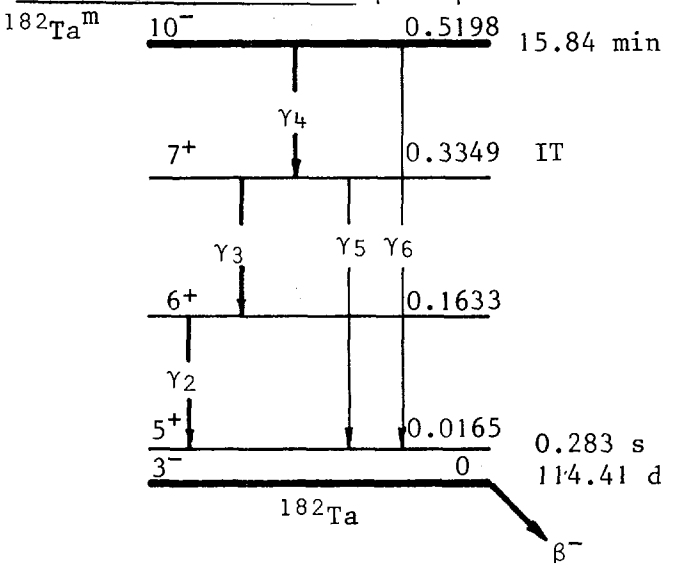
CTR

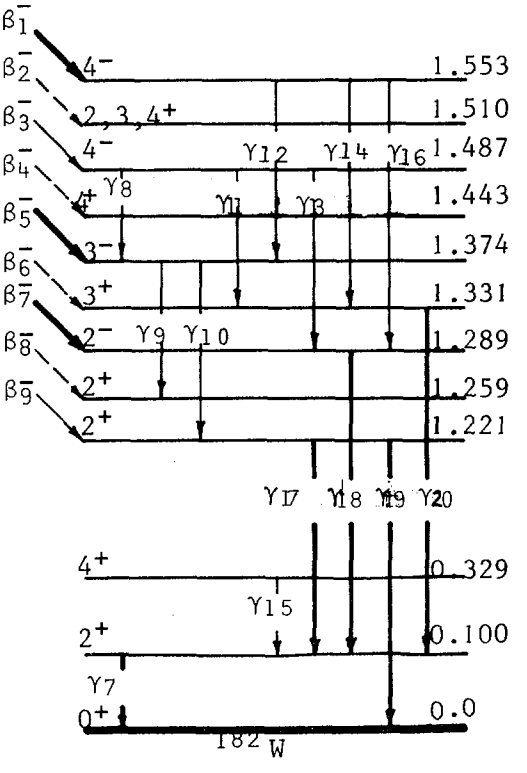
$^{181}Ta\ (n,\gamma)\ ^{182}Ta$

Material constants

Relative atomic mass of element	: $A_r(Ta)$	= 180.9479(3)	|Ho79|
Mass density	: ρ	= 16.654 $Mg.m^{-3}$	|We79|
Melting point	: T	= 3269.15 K = 2996 °C	|We79|
Number of atoms per unit mass	: N_m	= $3.328\times10^{24}kg^{-1}$	
Number of atoms per unit volume	: N_v	= $55.43\times10^{27}m^{-3}$	
Isotopic mole fractions	: $x(^{180}Ta)$	= 0.012(1)%	|Ho79|
	$x(^{181}Ta)$	= 99.988(1)%	|Ho79|

Disintegration scheme |Sc75|





Disintegration data |MED78|, |PTB79|

$^{182}Ta^{m}$ half-life : $T_{\frac{1}{2}}$ = 15.84(10) min

decay constant : λ = $7.2932 \times 10^{-4} s^{-1}$

	E(γ) (in keV)	Pγ (in %)
γ_2	146.785(15)	34.8(24)
γ_3	171.586(15)	45.7(21)
γ_4	184.951(15)	22.9(17)
γ_5	318.40 (5)	6.4 (6)
γ_6	356.47 (10)	0.27(5)

^{182}Ta half-life : $T_{\frac{1}{2}}$ = 114.41(2) d

decay constant : λ = $7.01209 \times 10^{-8} s^{-1}$

	E(β) max (in keV)	E(β)av (in keV)	Pβ (in %)
β_1^-	258(3)	71.5 (9)	28.6(10)
β_2^-	301(3)	84.7(10)	0.13
β_3^-	324(3)	91.8(10)	2.70(20)
β_4^-	368(3)	105.9(10)	0.66(4)
β_5^-	437(3)	128.5(10)	20 (3)
β_6^-	480(3)	142.8(11)	2.3
β_7^-	522(3)	157.1(11)	40 (5)
β_8^-	554(3)	168.0(11)	0.5
β_9^-	590(3)	180.6(11)	5.0(20)
Total β^-		126.2(12)	100 (7)

4 weak β^-s omitted ($\Sigma P\beta$ = 0.15%)

main γ-rays

	E(γ) (in keV)	Pγ (in %)
γ_7	100.1064 (3)	14.23 (42)
γ_8	113.6670(12)	1.87 (6)
γ_9	116.4149(17)	0.445(15)
γ_{10}	152.4281(14)	6.95 (9)
γ_{11}	156.3817(12)	2.63 (5)
γ_{12}	179.3904(18)	3.09 (4)
γ_{13}	198.3477(22)	1.44 (2)
γ_{14}	222.1010(20)	7.50 (10)

γ_{15}	229.316 (3)	3.64 (5)
γ_{16}	264.071 (5)	3.62 (6)
γ_{17}	1121.28 (3)	35.30 (32)
γ_{18}	1189.04 (4)	16.44 (15)
γ_{19}	1221.418(25)	27.17 (25)
γ_{20}	1230.97 (3)	11.58 (11)

Activities induced in tantalum

$^{181}Ta(n,\gamma)$ $^{182}Ta^{m}$; $T_{\frac{1}{2}}$ = 15.84 min |MED78| ;σ_0 =10.3(25) mb = 1.03 fm^2 |Mu73|
I =300 mb = 30 fm^2 |Wa77|

$^{181}Ta(n,\gamma)$ ^{182}Ta ; $T_{\frac{1}{2}}$ = 114.41 d |PTB79| ;σ_0 =21.0(7) b = 2100 fm^2 |Mu73|
I =720 b = 72000 fm^2 |Wa77|

$^{182}Ta(n,\gamma)$ ^{183}Ta ; $T_{\frac{1}{2}}$ = 5.0 d |Wa77| ;σ_0 =8200(600) b =820000 fm^2 |Mu73|
I =1000(100) b =100000 fm^2 |Mu73|

$^{181}Ta(n,\alpha)$ ^{178}Lu ; $T_{\frac{1}{2}}$ = 28.4 min |Wa77| ;$\langle\sigma\rangle$=(1.6(8))x10^{-4}mb=16 am^2 |Ca74|

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : for a ^{235}U fission spectrum:

(for a Watt representation): $\langle\sigma\rangle_c$= 0.1036 b = 10.36 fm^2
$g\sigma_0$ = 21.03 b = 2103 fm^2
I = 763.4 b = 76340 fm^2 |Zij77|

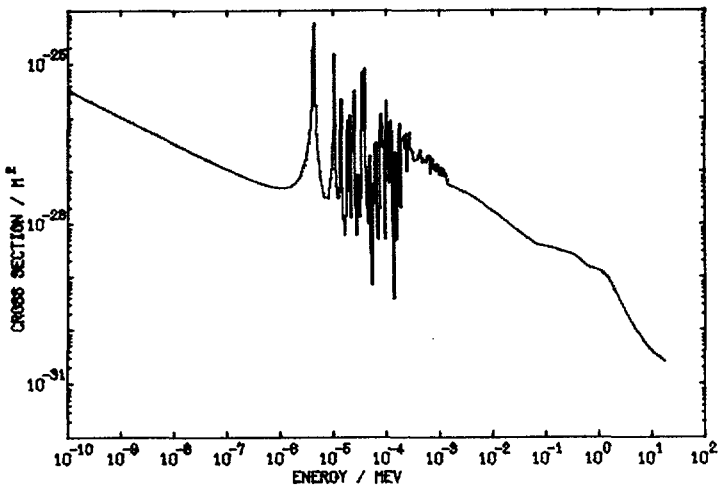
Response data

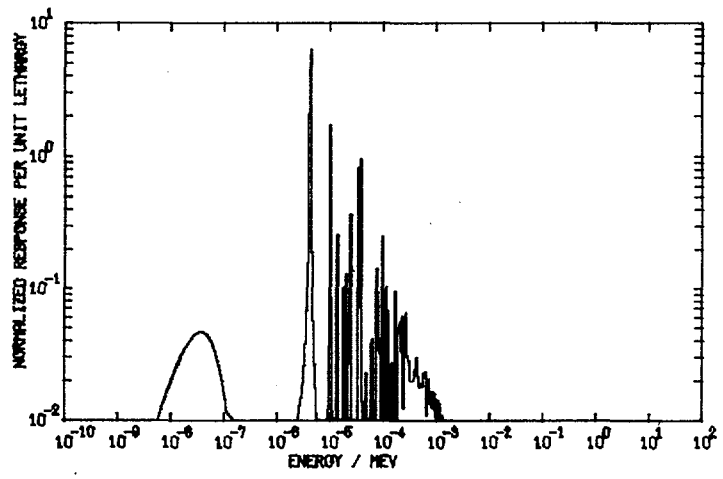
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: TA181(N,G)TA182

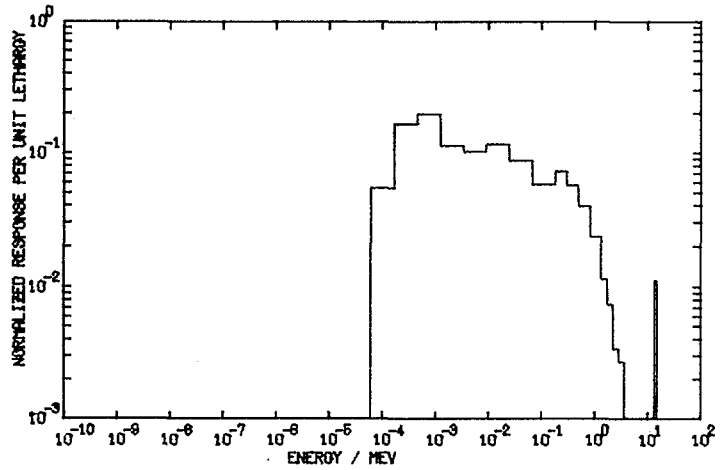
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	6.1E-05	3.0E-01	1.7E-04	2.5E-02	4.5E-04	9.1E-03	1.2E-03
252CF	6.9E-02	2.6E+00	2.7E-01	1.5E+00	4.5E-01	1.0E+00	7.2E-01
235U	5.8E-02	2.5E+00	2.4E-01	1.4E+00	4.3E-01	1.0E+00	6.9E-01
CFRMF	9.6E-05	6.9E-01	4.0E-04	2.0E-01	1.1E-03	4.3E-02	5.0E-03
SIG.SIG.	3.8E-05	8.0E-01	4.5E-04	2.7E-01	2.7E-03	9.6E-02	1.8E-02
MTR	2.8E-08	2.3E-04	4.0E-06	3.4E-05	4.3E-06	1.0E-05	4.3E-06

ALL ENERGY VALUES IN MEV.





MTR



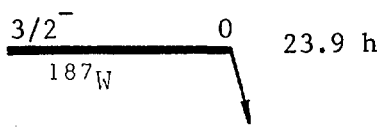
CTR

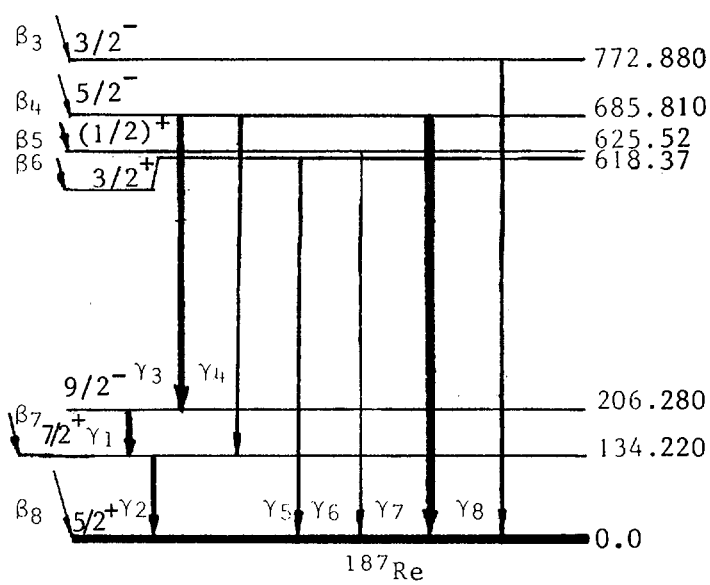
$^{186}W\ (n,\gamma)\ ^{187}W$

Material constants

Relative atomic mass of element	: $A_r(W)$	= 183.85(3)	|Ho79|
Mass density	: ρ	= 19.35 $Mg.m^{-3}$	|We79|
Melting point	: T	= 3683.15 K = 3410 °C	|We79|
Number of atoms per unit mass	: N_m	= $3.276\times10^{24} kg^{-1}$	
Number of atoms per unit volume	: N_v	= $63.39\times10^{27} m^{-3}$	
Isotopic mole fractions	: $x(^{180}W)$	= 0.13(1)%	Ho79
	$x(^{182}W)$	= 26.3 (1)%	Ho79
	$x(^{183}W)$	= 14.3 (1)%	Ho79
	$x(^{184}W)$	= 30.7 (1)%	Ho79
	$x(^{186}W)$	= 28.6 (1)%	Ho79

Disintegration scheme





Disintegration data |MED78|

^{187}W : half-life : $T_{\frac{1}{2}}$ = 23.9(1) h.

decay constant : λ = $8.056 \times 10^{-6} s^{-1}$

	$E(\beta^-)$ max (in keV)	$E(\beta^-)$ av (in keV)	P_β (in %)
β_1^-	433.5(18)	127.1(6)	0.478(19)
β_2^-	448.4(18)	132.1(6)	0.603(24)
β_3^-	540.0(18)	163.1(7)	4.33 (20)
β_4^-	627.1(18)	193.6(7)	58.9 (22)
β_5^-	687.4(18)	215.2(7)	1.56 (7)
β_6^-	694.5(18)	217.8(7)	7.2 (3)
β_7^-	1178.7(18)	401.9(7)	1.7 (10)
β_8^-	1312.9(18)	457.3(8)	25.1 (24)
total β^-		263.2(9)	100 (4)

9 weak β's omitted : $\Sigma P\beta$ = 0.37 %.

	$E(\gamma)$ (in keV)	P_γ (in %)
γ_1	72.060(10)	11.9 (5)
γ_2	134.220(10)	9.4 (4)
γ_3	479.530(10)	23.4 (10)
γ_4	551.550(10)	5.45(22)
γ_5	618.370(10)	6.7 (3)
γ_6	625.520(10)	1.17 (5)
γ_7	685.810(10)	29.3 (12)
γ_8	772.880(20)	4.42(18)

Activity induced in tungsten

$^{180}W(n,\gamma)^{181}W$: $T_{\frac{1}{2}}$ = 121.2(3) d |Ma76|

σ_{act} = 350 fm^2 |Mu73|

I = 20000 fm^2

$^{184}W(n,\gamma)^{185}W$: $T_{\frac{1}{2}}$ = 75.1(3) d |Ma76|

σ_{act} = 180 (20) fm^2 |Mu73|

I = 1400(200) fm^2

$^{184}W(n,\gamma)^{185}W^m$: $T_{\frac{1}{2}}$ = 1.65 min

σ_{act} = 0.20(10) fm^2 |Mu73|

$^{186}W(n,\gamma)^{187}W$: $T_{\frac{1}{2}}$ = 23.9(1) h |MED78|

σ_{act} = 3780 (150) fm^2 |Mu73|

I = 50000(3500) fm^2

Evaluated cross section data and response data

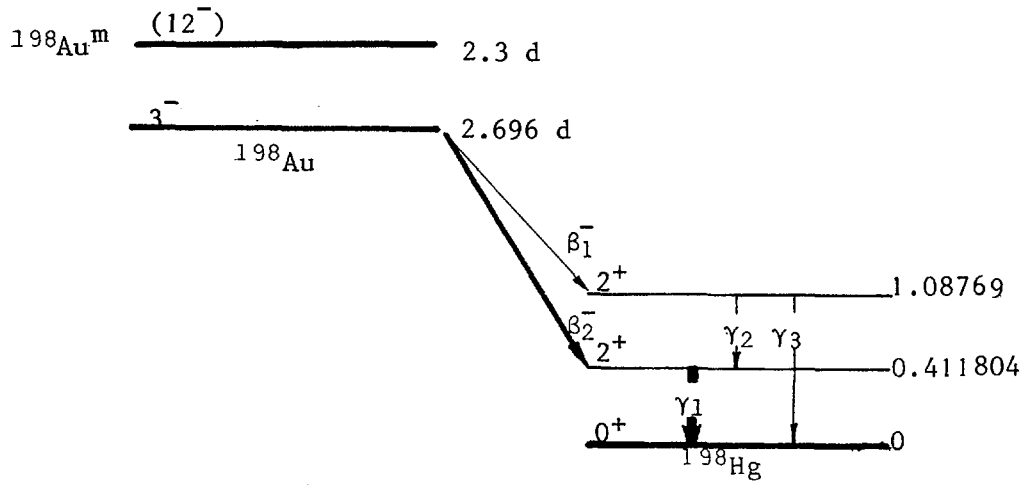
No data available.

$^{197}Au(n,\gamma)^{198}Au$

Material constants

+ Relative atomic mass of element	: $A_r(Au)$	= 196.9665(1)	|Ho79|,	|We79|
Mass density	: ρ	= 19.32 $Mg.m^{-3}$		
Melting point	: T	= 1337.58 K = 1064.43°C		
Number of atoms per unit mass	: N_m	= $3.058\times10^{24}kg^{-1}$		
Number of atoms per unit volume	: N_v	= $59.07\times10^{27}m^{-3}$		
Isotopic mole fraction	: $x(^{197}Au)$	= 100%	|Ho79|	

Disintegration scheme



Disintegration data |MED78|.

+ ^{198}Au: half-life = 2.696(2) d
+ = $2.9757\times10^{-6}s^{-1}$
+ $E(\beta_1)$ max 285.3(6) keV; average 79.60(20) keV; (1.30(10)%)
+ $E(\beta_2)$ max 961.2(6) keV; average 314.80(20) keV; (98.70(10)%)
+ total β^- average 311.78(21) keV; (100.02(15)%)
+ $E(\gamma_1)$ 411.8044(1) keV 95.404(19)%
+ $E(\gamma_2)$ 675.890 (4) keV 1.06 (5)%
+ $E(\gamma_3)$ 1087.692(24) keV 0.23 (6)%

Activities induced in gold

$^{197}Au(n,\gamma)^{198}Au$

+ $T_{\frac{1}{2}} \doteq 2.696$ d |MED78| $\sigma_{act} = 9880(30)$ fm^2 |Mu73|

$I = 156000(4000)$ fm^2 |Ji60| $I' = 149000(4000)$ fm^2 |Ji60|

g value of Westcott convention 1.01

s_0 value of Westcott convention 17.02

$^{198}Au(n,\gamma)^{199}Au$ $T_{\frac{1}{2}} = 3.139$ d |MED78| $\sigma_{act} = 2580000(120000)$ fm^2

$^{199}Au(n,\gamma)^{200}Au$ $T_{\frac{1}{2}} = 48.4$ min |Se74| $\sigma_{act} = 3000(1500)$ fm^2 } |Mu73|

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : $g.\sigma_0 = 9976$ fm^2 |Zij77|

$I = 156400$ fm^2 |Zij77|

Remark

The isomeric state of $^{198}Au^m$ with half-life of 2.3 d |Wa77| is not formed by neutron irradiation of ^{197}Au.

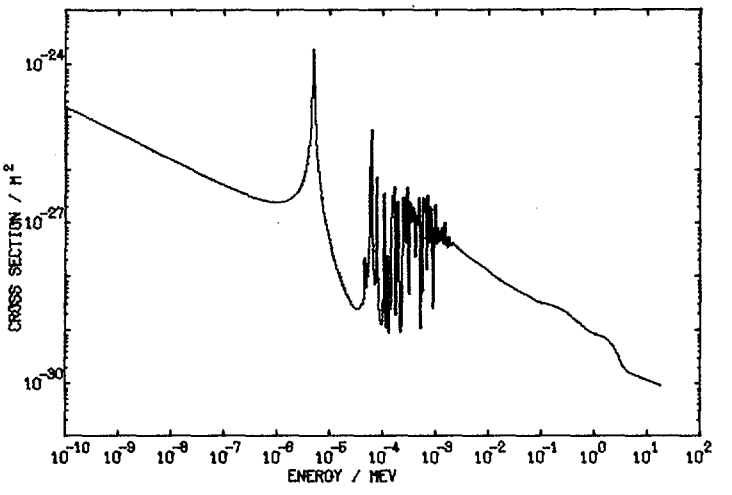
Response data

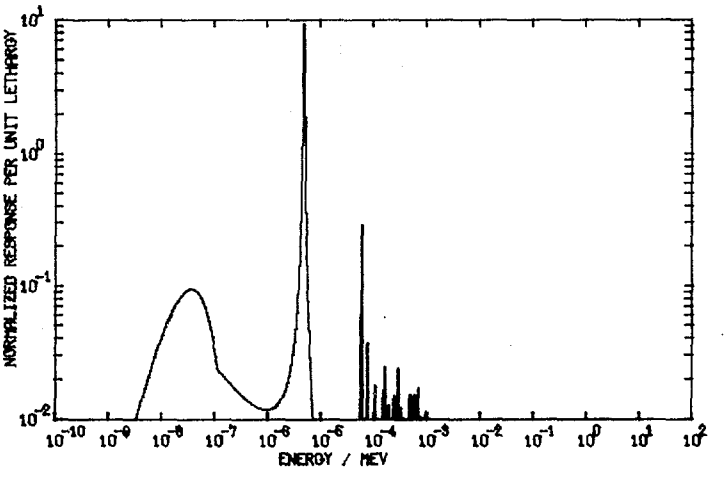
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: AU197(N,G)AU198

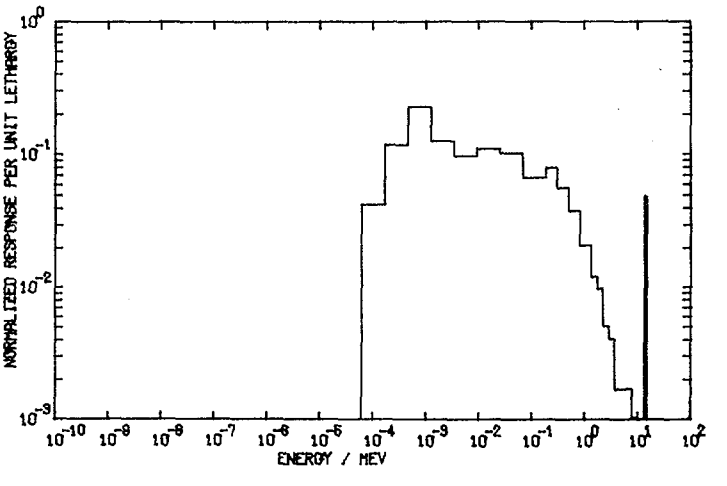
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	1.7E-04	3.0E-01	4.5E-04	2.5E-02	4.5E-04	9.1E-03	1.2E-03
252CF	6.6E-02	3.0E+00	2.6E-01	1.7E+00	4.5E-01	1.1E+00	7.2E-01
235U	5.8E-02	2.9E+00	2.4E-01	1.6E+00	4.3E-01	1.1E+00	6.9E-01
CFRMF	1.5E-04	6.6E-01	6.0E-04	2.0E-01	1.4E-03	5.8E-02	7.2E-03
SIG.SIG.	5.0E-06	7.6E-01	3.8E-04	2.4E-01	1.8E-03	8.4E-02	1.7E-02
MTR	1.5E-08	5.8E-06	1.2E-07	4.8E-06	4.5E-06	4.8E-06	4.8E-06

ALL ENERGY VALUES IN MEV.





MTR



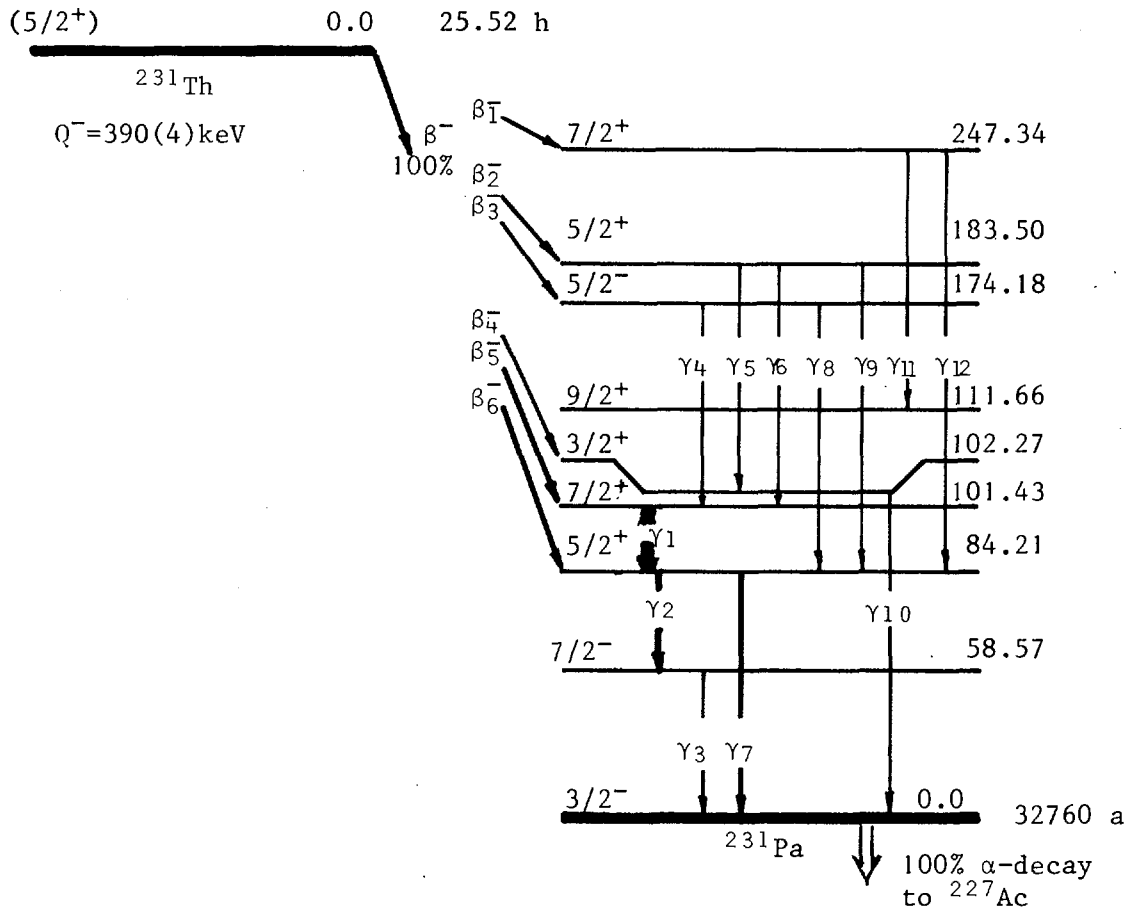
CTR

$^{232}Th\ (n,2n)\ ^{231}Th$

Material constants

Relative atomic mass of element	: $A_r(Th)$	= 232.0381(1)	|Ho79|, |We79|
Mass density	: ρ	= 11.72 $Mg.m^{-3}$	|We79|
Melting point	: T	= 2023.15 K = 1750°C	|We79|
Number of atoms per unit mass	: N_m	= $2.595\times10^{24}kg^{-1}$	
Number of atoms per unit volume	: N_v	= $30.42\times10^{27}m^{-3}$	
Isotopic mole fraction	: $x(^{232}Th)$	= 100%	|Ho79|

Disintegration scheme |Sc77|



Disintegration data |MED78|

^{231}Th: half-life : $T_{\frac{1}{2}}$ = 25.52(1) h
decay constant: λ = $7.5447\times10^{-6}s^{-1}$

β^- number	E_{β^-} max (in keV)	E_{β^-} av (in keV)	P_β (in %)
1	143(4)	37.6(12)	2.8 (5)
2	172(4)	45.8(12)	0.32(20)
3	207(4)	55.7(12)	12.8 (11)
4	216(4)	58.4(12)	1.30(20)
5	288(4)	79.6(12)	12 (7)
6	289(4)	79.9(12)	37 (15)
7	306(4)	85.1(13)	35 (20)
total		77.0(13)	100 (30)

6 weak β's omitted ΣP_β = 0.09%

γ number	$E\gamma$ (in keV)	$I\gamma$ (in %)
1	25.64(2)	14.8 (13)
2	17.2 (7)	44 (16)
3	58.57(2)	0.48 (4)
4	72.78(2)	0.251(20)
5	81.24(2)	0.89 (7)
6	82.11(2)	0.40 (4)
7	84.21(2)	6.5 (6)
8	89.95(2)	0.94 (8)
9	99.28(2)	0.120(10)
10	102.27(2)	0.41 (4)
11	163.12(2)	0.155(12)

37 weak γ's omitted

^{231}Pa : half-life : $T_{\frac{1}{2}}$ = 32760(110) a* |Sc77|, |Lo78|.

* 1 a = 365.24220 d = 31556926 s |ISO75|

Activities induced in thorium (other than of fission products)

^{232}Th(n,γ)^{233}Th ; $T_{\frac{1}{2}}$ = 22.3(1) min |E178|; σ_0= 7.40(8) b=740 fm^2 } |Mu73|
I = 85(3) b = 8500 fm^2 }

^{232}Th(n,2n)^{231}Th; $T_{\frac{1}{2}}$ = 25.52(1) h |MED78| $\langle\sigma\rangle$= 14.2(11)mb=1.42 fm^2 |Ca74|

Evaluated cross section data

620 group data : |La75|, |Zij77|

Integral data : for a ^{235}U fission spectrum

(for a Watt representation): $\langle\sigma\rangle_c = 15.03$ mb $= 1.503$ fm^2 |Zij77|

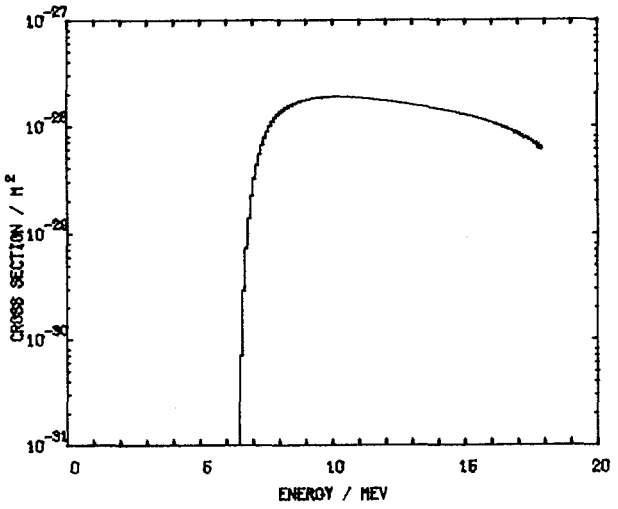
Response data

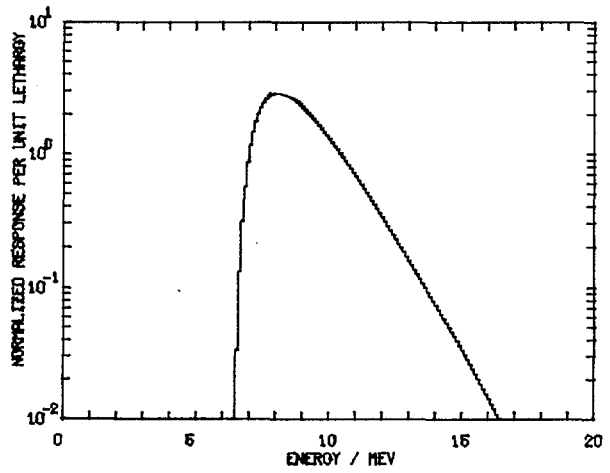
See next page.

RESPONSE DATA FOR THE REACTION: TH232(N,2N)231TH

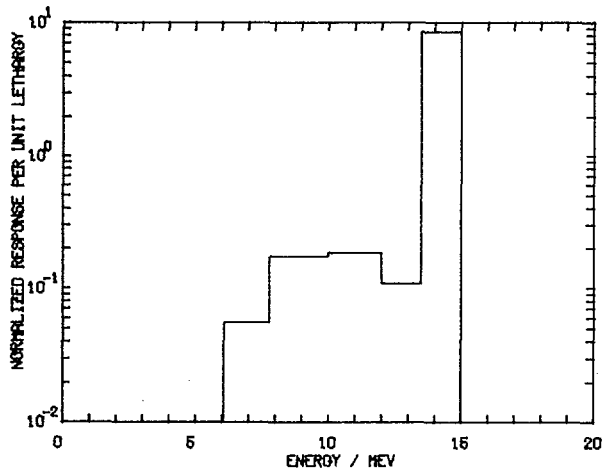
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	7.8E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	7.1E+00	1.2E+01	7.6E+00	9.8E+00	8.0E+00	9.0E+00	8.5E+00
235U	7.0E+00	1.1E+01	7.5E+00	9.6E+00	7.9E+00	8.8E+00	8.3E+00
CFRMF	7.1E+00	1.2E+01	7.6E+00	9.7E+00	8.0E+00	8.9E+00	8.4E+00
SIG.SIG.	7.0E+00	1.1E+01	7.5E+00	9.6E+00	7.9E+00	8.9E+00	8.4E+00
MTR	7.1E+00	1.2E+01	7.6E+00	9.8E+00	8.0E+00	9.0E+00	8.5E+00

ALL ENERGY VALUES IN MEV.





MTR

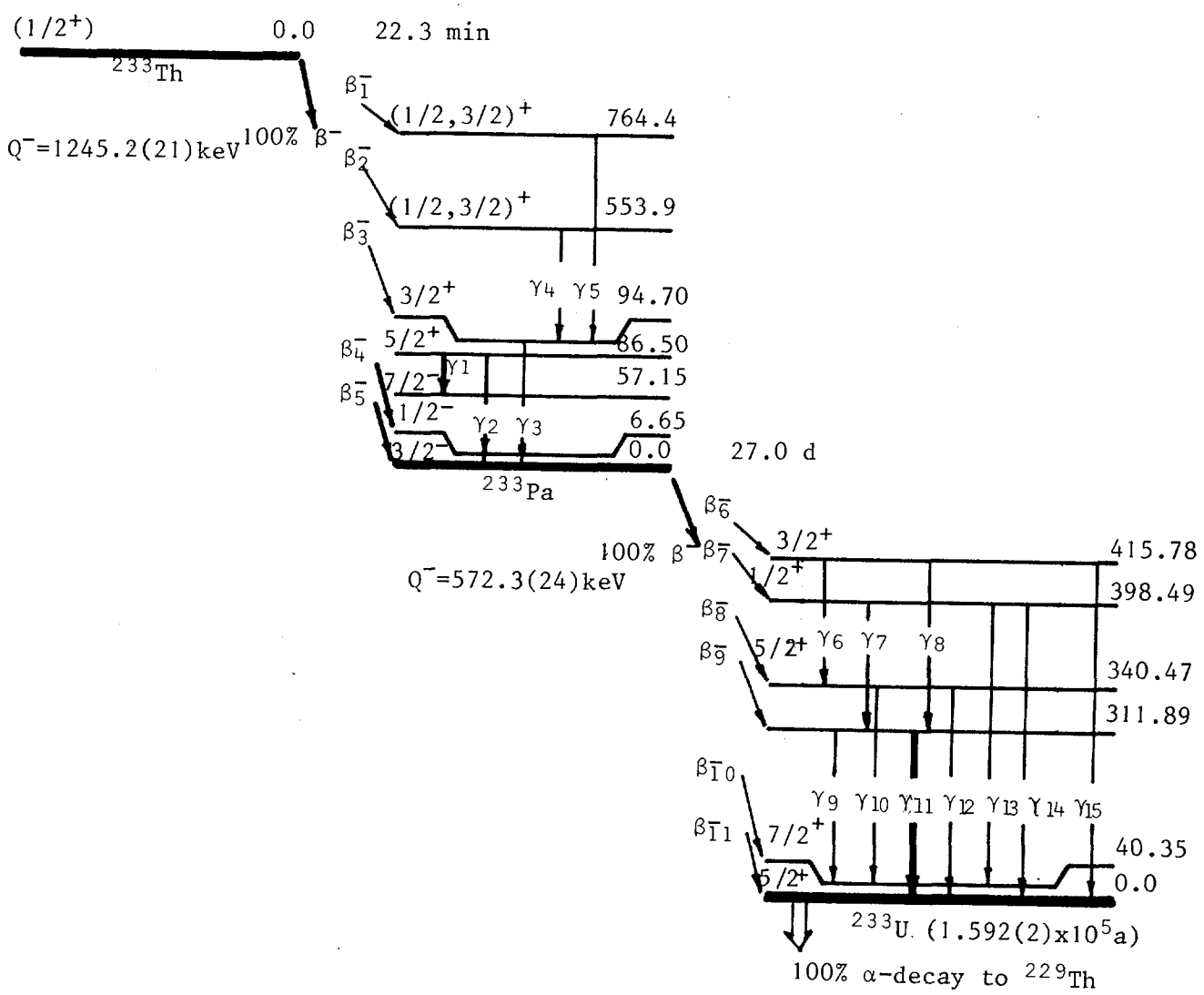


CTR

$^{232}Th\,(n,\gamma)\,^{233}Th \xrightarrow{\beta} {}^{233}Pa$

Material constants see reaction $^{232}Th(n,2n)^{231}Th$

Disintegration scheme |E178|



Disintegration data ^{233}Th |E178|, ^{233}Pa |Ko77|.

^{233}Th : half-life : $T_{\frac{1}{2}}$ = 22.3(1) min

decay constant : λ = $5.1805 \times 10^{-4} s^{-1}$

100 % β^- decay to ^{233}Pa (see remark).

β^-number	$E(\beta^-)$max (in keV)	E level (in keV)	P_β(in %)
1	480.8(21)	764.4	1.58
2	691.3(21)	553.9	1.7
3	1150.5(21)	94.70	∿16
4	1238.6(21)	6.65	∿50
5	1245.2(21)	0.0	∿30

10 weak β's omitted $\Sigma P\beta$ = 3.6 %.

γ number	$E(\gamma)$ (in keV)	P_γ(in %)
1	29.36(4)	2.5
2	86.50(5)	2.7
3	94.68(5)	0.8
4	459.2 (2)	1.4
5	669.8 (2)	0.68

relative γ-ray emission probabilities were normalized to 2.7 % for 86.50 keV.

^{233}Pa : half-life : $T_{\frac{1}{2}}$ = 27.0(1) d.

decay constant : λ = $2.9713 \times 10^{-7} s^{-1}$

100 % β^- decay to ^{233}U.

β^-number	$E(\beta^-)$max (in keV)	$E(\beta^-)$av (in keV)	P_β (in %)
6	156.6(24)	41.5(7)	21.49(20)
7	173.8(24)	46.3(7)	14.97(7)
8	231.8(24)	63.0(7)	36.3 (8)
9	260.4(24)	71.4(8)	16.88(18)
10	532.0(24)	160.6(8)	1.2 (7)
11	572.3(24)	170.3(8)	9.2 (4)
total β^-		68.3(9)	100.0(12)

γ number	E(γ) (in keV)	Pγ (in %)
6	75.280(20)	1.1458
7	86.590(20)	1.786
8	103.864(10)	0.59 (3)
9	271.58 (4)	0.84 (5)
10	300.124(20)	5.8 (3)
11	311.887(10)	33.7
12	340.470(20)	3.88 (21)
13	375.40 (5)	0.59 (3)
14	398.490(20)	1.29 (7)
15	415.780(20)	1.59 (8)

12 weak γ's omitted : Eγ av 88.8 ΣPγ = 0.19 %.

relative γ-ray emission probabilities were normalized to 33.7 % for 311.887 keV.

added in proof : γ-ray emission probability for 311.887 keV is 38.6(4) % :|E178| (private comm. from R.J. Gehrke and C.W. Reich (May 1978)).

^{233}U : half-life : $T_{\frac{1}{2}}$ = (1.592(2)x10^5a |Lo78|
(1a = 365.24220 d = 31556926 s |IS075|)

Activities induced in thorium (other than of fission products)

see the reaction $^{232}Th(n,2n)^{231}Th$

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : for a ^{235}U fission spectrum :

(for a Watt representation) $\langle\sigma\rangle_c$= 0.1019 b = 10.19 fm^2
$g\sigma_o$ = 7.396 b = 739.6 fm^2
I = 85.12 b = 8512 fm^2 } |Zij77|

$\langle\sigma\rangle_c$= 103.8 mb = 10.38 fm^2
I = 85.58 b = 8558 fm^2 } |Ma75,2|

Remark

For the ^{233}Th β^- decay : the β intentities were deduced from intensity imbalance at each level. The summed β^- intensity is $\simeq$ 103%. More precise measurements of absolute P_γ and P_{ce} are needed.

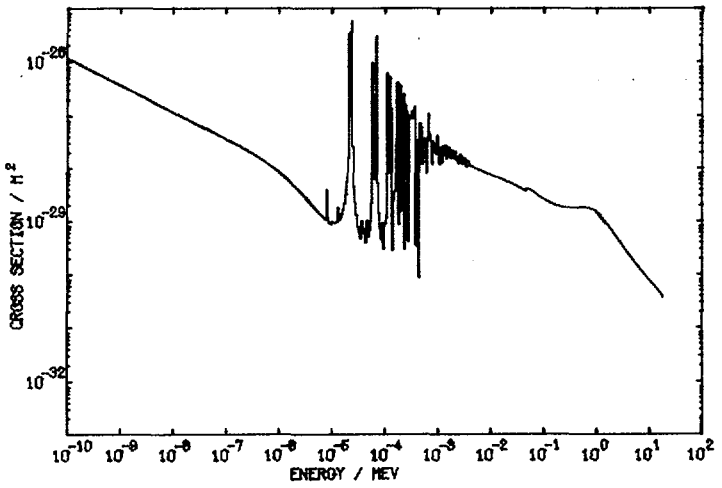
Response data

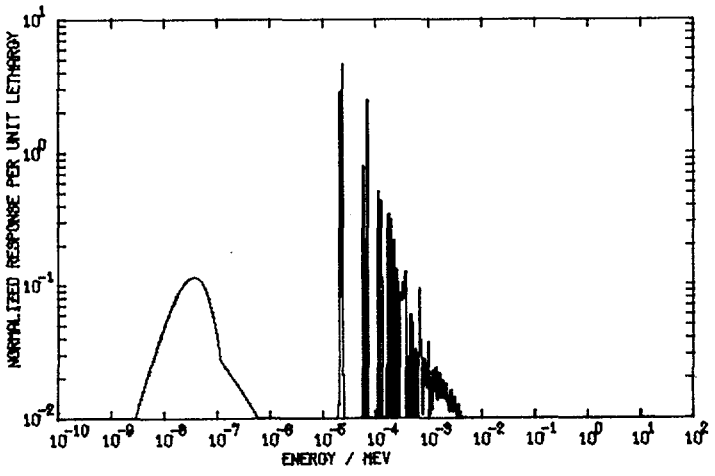
See next page.

RESPONSE DATA FOR THE REACTION: TH232(N,G)TH233

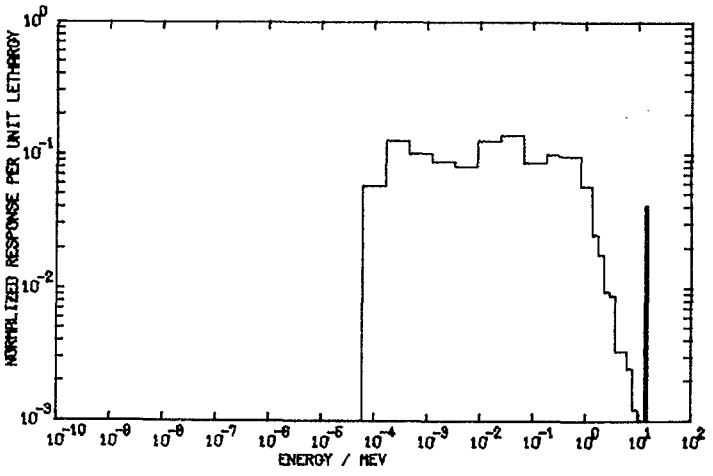
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	6.1E-05	8.2E-01	4.5E-04	6.8E-02	1.2E-03	2.5E-02	9.1E-03
252CF	1.1E-01	3.1E+00	3.8E-01	1.7E+00	6.3E-01	1.1E+00	8.8E-01
235U	9.2E-02	2.9E+00	3.6E-01	1.6E+00	6.0E-01	1.1E+00	8.4E-01
CFRMF	1.3E-04	1.0E+00	9.6E-04	4.3E-01	1.2E-02	1.9E-01	6.3E-02
SIG.SIG.	6.9E-05	1.1E+00	3.0E-03	5.0E-01	3.0E-02	2.6E-01	1.0E-01
MTR	1.2E-08	1.9E-03	5.8E-08	1.2E-04	2.1E-05	5.8E-05	2.3E-05

ALL ENERGY VALUES IN MEV.





MTR



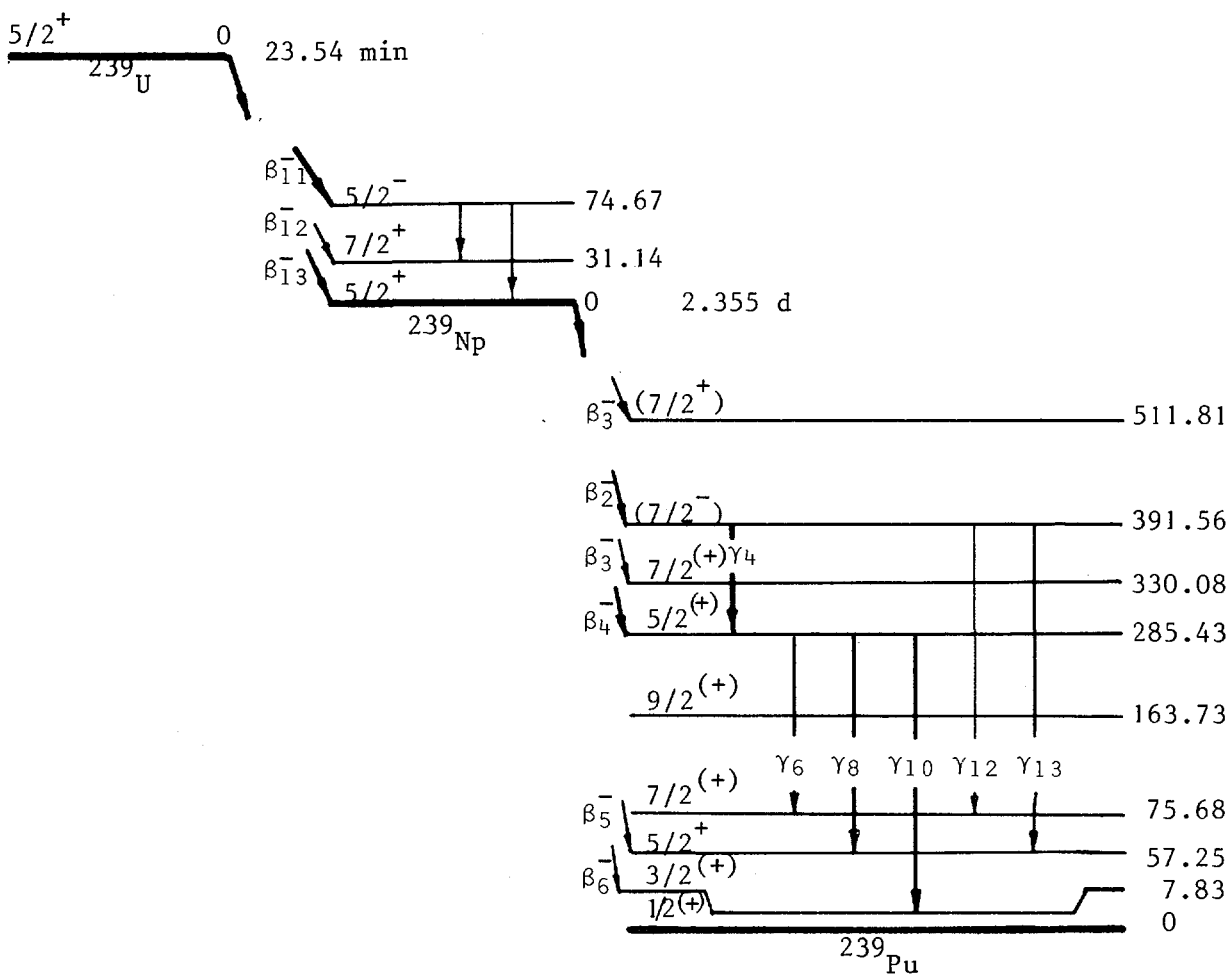
CTR

$^{238}U(n,\gamma)^{239}U \xrightarrow{\beta} {}^{239}Np$

Material constants

+ Relative atomic mass of element	: $A_r(U)$	= 238.029(1)	|Ho79|,	|We79|
Mass density	: ρ	= 19.05(2) $Mg.m^{-3}$		
Melting point	: T	= 1405.45 K = 1132.3(8) °C		
Number of atoms per unit mass	: N_m	= $2.530\times10^{24} kg^{-1}$		
Number of atoms per unit volume	: N_v	= $48.20\times10^{27} m^{-3}$		
Isotopic mole fractions	: natural uranium			
	$x(^{234}U)$	= 0.0054(1)%		
	$x(^{235}U)$	= 0.720 (1)%		|Ho79|
	$x(^{238}U)$	=99.275 (1)%		

Disintegration scheme



Disintegration data |MED78|

^{239}U : half-life = 23.54(5) min

λ = $0.49076\times10^{-3}s^{-1}$

+	$E(\beta^-_{11})$ max 1192(3) keV; av 392.4(12) keV		(73(10)%)
+	$E(\beta^-_{12})$ max 1236(3) keV; av 408.9(12) keV		(6%)
+	$E(\beta^-_{13})$ max 1267(3) keV; av 420.8(12) keV		(19(8)%)

Six other β's with P_β< 0,3% omitted.

$E(\gamma)$	74.670(3) keV	(50(5)%)
$E(\gamma)$	43.534(3) keV	(4.4(5)%)

many other γ's with P_γ< 0.2% omitted.

^{239}Np: β^- decay

half-life = 2.355(4) d

λ = $3.4066\times10^{-6}s^{-1}$

	$E(\beta^-_1)$	max	211(3)	keV	
+		av	57.0(10)	keV	(1.80(20)%)
+	$E(\beta^-_2)$	max	332(3)	keV	
		av	93.0(10)	keV	(33.0(20)%)
	$E(\beta^-_3)$	max	393(3)	keV	
+		av	112.0(10)	keV	(7(3)%)
	$E(\beta^-_4)$	max	438(3)	keV	
+		av	126.0(10)	keV	(53(5)%)
+	$E(\beta^-_5)$	max	666(3)	keV	
		av	201.0(10)	keV	(2.0(10)%)
	$E(\beta^-_6)$	max	715(3)	keV	
		av	219.0(10)	keV	(4.0(20)%)
+	Total β^-	av	118.1(11)	keV	(101(7)%)

++	$E(\gamma_1)$	49.410(20)	keV	(0.100(22)%)
+	$E(\gamma_2)$	57.260(20)	keV	(0.151(21)%)
+	$E(\gamma_3)$	61.480(4)	keV	(0.96(15)%)
	$E(\gamma_4)$	106.130(10)	keV	(22.7(13)%)
	$E(\gamma_5)$	181.71(6)	keV	(0.111(15)%)
	$E(\gamma_6)$	209.750(10)	keV	(3.24(25)%)
+	$E(\gamma_7)$	226.42(8)	keV	(0.34(5)%)
	$E(\gamma_8)$	228.190(10)	keV	(10.7(7)%)
	$E(\gamma_9)$	254.41(8)	keV	(0.100(18)%)

	$E(\gamma_{10})$ 277.60(3)	keV	(14.1(4)%)
	$E(\gamma_{11})$ 285.41(3)	keV	(0.78(8)%)
	$E(\gamma_{12})$ 315.88(4)	keV	(1.59(11)%)
	$E(\gamma_{13})$ 334.30(5)	keV	(2.03(18)%)
+	20 weak γ's omitted ($\Sigma P\gamma$ = 0.37%)		

Activities induced in uranium

$^{238}U(n,\gamma)^{239}U$	$T_{\frac{1}{2}}$ = 23.54min |MED78|	σ_{act} = 270(2) fm^2	|Mu73|
	I_γ = 27500(500) fm^2 |Mu73|		
	g value Westcott conv. 1.0019		
	s_0 value Westcott conv. 117.9		|Oka70|
$^{239}U(n,\gamma)^{240}U$	$T_{\frac{1}{2}}$ = 14.1 h |Se74|	σ_{act} = 2200(500) fm^2	
$^{239}U(n,f)FP$		σ_f = 1400(300) fm^2	
+ $^{234}U(n,\gamma)^{235}U$	$T_{\frac{1}{2}}$ = 7.038×10^8 a |Lo78|	σ_{act} = 10020(150) fm^2	
$^{234}U(n,f)FP$		σ_f < 65 fm^2	
$^{235}U(n,\gamma)^{236}U$	$T_{\frac{1}{2}}$ = 2.342×10^7 a |Lo78|	σ_{act} = 9860(150) fm^2	
$^{235}U(n,f)FP$		σ_f = 58220(130) fm^2	|Mu73|
$^{236}U(n,\gamma)^{237}U$	$T_{\frac{1}{2}}$ = 6.75 d |Lo78|	σ_{act} = 520(30) fm^2	
$^{237}U(n,\gamma)^{238}U$	$T_{\frac{1}{2}}$ = 4.468×10^9 a |Lo78|	σ_{act} = 41100(13800) fm^2	
$^{237}U(n,f)FP$		σ_f < 35 fm^2	
$^{239}Np(n,\gamma)^{240}Np^m$	$T_{\frac{1}{2}}$ = 7.4 min |Se74|	σ_{act} = 3100(600) fm^2	
$^{239}Np(n,\gamma)^{240}Np$	$T_{\frac{1}{2}}$ = 65 min |Se74|	σ_{act} = 1400(1400) fm^2	
$^{239}Np(n,f)FP$		σ_f < 100 fm^2	
+ $^{239}Pu(n,\gamma)^{240}Pu$	$T_{\frac{1}{2}}$ = 6553 a |Lo78|	σ_{act} = 26880(300) fm^2	
$^{239}Pu(n,f)FP$		σ_f = 74250(300) fm^2	
$^{238}U(n,f)$		$\langle\sigma\rangle_f$ = 30.5(10) fm^2	|Fa77|

Evaluated cross section data

620 group data : \|Ma75\|, \|Zij77\|

Integral data : $g.\sigma_0$ = 272 fm^2
I = 27690 fm^2 } \|Zij77\|

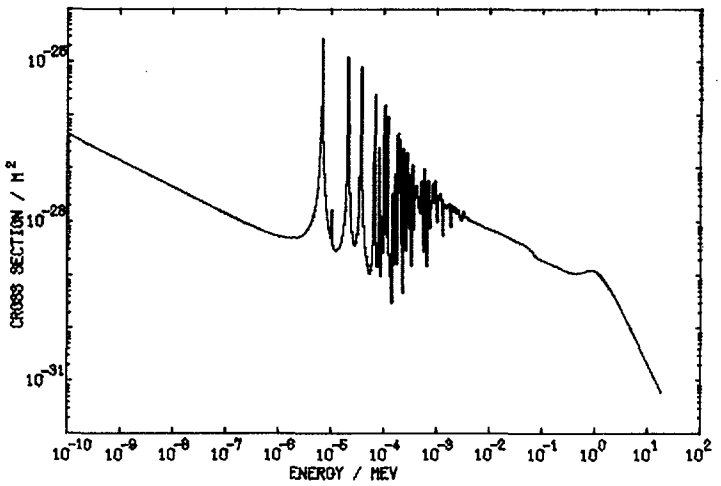
Response data

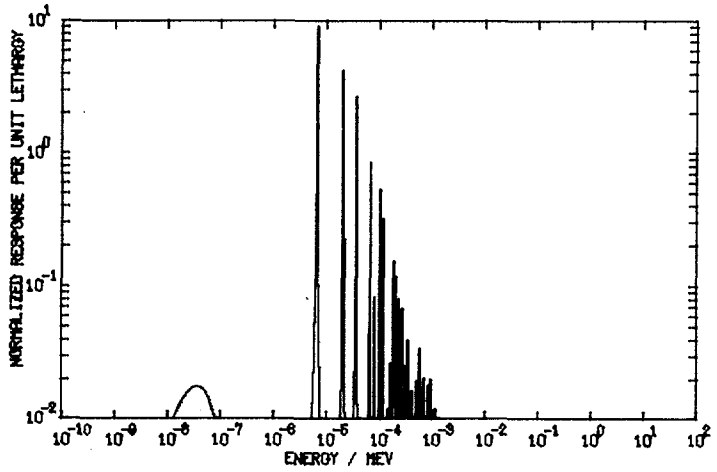
See next page.

RESPONSE DATA FOR THE REACTION: U238(N,G)U239

SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	6.1E-05	5.0E-01	4.5E-04	6.8E-02	1.2E-03	2.5E-02	9.1E-03
252CF	9.2E-02	2.8E+00	3.8E-01	1.6E+00	6.6E-01	1.2E+00	9.2E-01
235U	8.0E-02	2.7E+00	3.6E-01	1.6E+00	6.3E-01	1.1E+00	8.8E-01
CFRMF	6.6E-05	1.0E+00	6.0E-04	3.4E-01	4.0E-03	1.2E-01	3.2E-02
SIG.SIG.	3.8E-05	1.1E+00	8.4E-04	4.3E-01	1.4E-02	1.7E-01	5.3E-02
MTR	6.0E-06	2.0E-04	6.6E-06	3.6E-05	6.6E-06	2.0E-05	2.0E-05

ALL ENERGY VALUES IN MEV.





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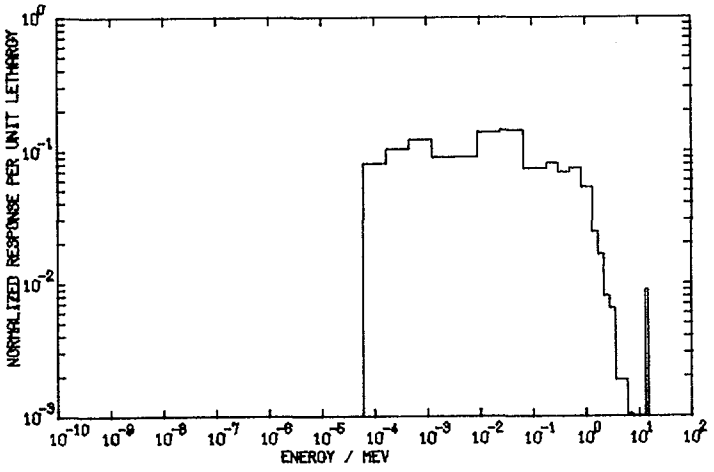

CTR

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Appendix 1: Reference file for cross section data

The ENDF/B-IV dosimetry file |Ma75, 1 and 2|, |Pa77| is now generally available and has been adopted for international comparisons as a reference cross section set. All users are requested to communicate their experience with this data file, so that future improvements aid to the aim of arriving at one generally accepted, internally consistent and extended dosimetry data file.

The dosimetry reactions have been classified in two categories |V177|.

Category I reactions are defined as reactions:

a) for which the energy dependent cross sections are well known over their response ranges in standard neutron fields;
b) for which calculated reaction rates in the standard neutron fields are consistent with the measured reaction rates.

The following reactions belong to category I: $^{197}Au(n,\gamma)^{198}Au$, $^{239}Pu(n,f)$, $^{237}Np(n,f)$, $^{238}U(n,f)$, $^{56}Fe(n,p)^{56}Mn$, $^{27}Al(n,\alpha)^{24}Na$, $^{63}Cu(n,2n)^{62}Cu$ and $^{58}Ni(n,2n)^{57}Ni$. (Remark: For the (n,2n) reactions with very high threshold energies, accuracies of about 10% are presently acceptable).

A number of other reactions are considered category I candidates: $^{59}Co(n,\gamma)^{60}Co$, $^{238}U(n,\gamma)^{239}U$, $^{115}In(n,n')^{115}In^{m}$, $^{58}Ni(n,p)^{58}Co$, $^{32}S(n,p)^{32}P$, $^{54}Fe(n,p)^{54}Mn$ and $^{59}Co(n,\alpha)^{56}Mn$.

All other reactions used for neutron metrology are category II reactions.

The ENDF/B- V dosimetry file is expected to become available in 1979. Furthermore the IAEA Nuclear Data Section (N.D.S.) will also in 1979 issue a cross section data file, called the International Reactor Dosimetry File (I.R.D.F.). This IRDF will initially comprise all reactron included in the ENDF/B-V dosimetry file, and in additon a set of reaction cross sections which are evaluated by groups outside the U.S.A., with a possible extension of the file to include additional reactions of interest.

Appendix 2: Fission spectrum representation

For the calculation of equivalent fission neutron fluences one needs the values for the cross sections of the activation (or fission) detectors used, and in particular the cross section averaged over a fission neutron spectrum.

For the fission neutron spectrum of ^{235}U several analytical representations have been used in the past years.

In the following expressions, which have been normalized to a value of unity, E denotes the neutron energy, expressed in MeV:

- the formula proposed by Watt |Wa52|

$$\chi_1(E) = 0.48395 \exp(-E).\sinh\sqrt{2E}$$

- the formula proposed by Cranberg, Frye et al. |Cr56|

$$\chi_2(E) = 0.45274 \exp(-E/0.965).\sinh\sqrt{2.29E}$$

- the formula of Maxwellian type proposed by Leachman |Le56|

$$\chi_3(E) = 0.76985 \exp(-E/1.29).\sqrt{E}$$

- the modified Watt-Cranberg formula proposed by Wood |Wo73|

$$\chi_4(E) = 0.5827 \exp(-0.992E).\sinh(1.27\sqrt{E})$$

The IAEA Consultants Meeting on prompt fission neutron spectra |IAEA72|, held in 1971, concluded that a simple Maxwellian form does not satisfactorily fit all observed fission spectra. It was felt then that for the present a purely numerical representation of experimental results would be best.

Magurno and Ozer |Ma75,1| tested the data on the ENDF/B-IV dosimetry file also by calculating spectrum averaged cross sections using the Maxwellian spectrum function:

$$\chi_5(E) = 0.770.\sqrt{E}.\exp(-E/T)$$

using

$$T = 1.29 \text{ MeV and } T = 1.32 \text{ MeV}.$$

Recently Grundl and Eisenhauer |Gr75|, |Gr77| from the National Bureau of Standards made a new evaluation, based on 16 documented differential spectrometry measurements of the thermal neutron induced ^{235}U fission neutron spectrum, and of the ^{252}Cf spontaneous fission neutron spectrum. Their results can be described in three forms:

1. A reference Maxwellian representation, obtained from a weighted least squares fit in the energy range from 0.25 MeV to 8 MeV.

   For ^{235}U : $\chi_6(E) = 0.7501.\sqrt{E}.\exp(-1.50E/1.97)$.

   For ^{252}Cf: $\chi_7(E) = 0.6672.\sqrt{E}.\exp(-1.50E/2.13)$.

2. A seven-group spectrum of adjusted Maxwellian segments, which fit the data over all energies. Estimated uncertainties are 1% to 4% for both spectra between 0.25 and 8 MeV and between 5 and 15% outside this energy range.
3. A continuous line segment correction to the reference Maxwellian, which establishes a final fit to the experimental data:

   For ^{235}U : $X_8(E) = \mu(E).X_6(E)$

   For ^{252}Cf: $X_9(E) = \mu(E).X_7(E)$

   Below 6 MeV the correction function $\mu(E)$ is linear, above 6 MeV it is exponential. The correction functions for the two spectra are as follows:

energy interval (in MeV)	$\mu(E)$ for ^{235}U	$\mu(E)$ for ^{252}Cf
0 to 0.25	1+0.800E-0.153	1+1.200E-0.237
0.25 to 0.8	1-0.140E+0.082	1-0.140E+0.098
0.8 to 1.5	1+0.040E-0.062	1+0.024E-0.0332
1.5 to 6.0	1+0.010E-0.017	1+0.0006E+0.0037
6.0 to ∞	1.043{exp -0.06(E-6.0)/1.043}	1.0 exp{-0.03(E-0.60)/1.0}

Similar representationshave been tried for the spontaneous fission neutron spectrum of ^{252}Cf:

- A formula proposed by Knitter et al |Kn73|, using a Maxwellian function with an average energy <E> = 2.13 MeV;
- A more complicated function used by Green |Gr73|, based on a detailed evaporation model, and yielding an average energy <E> = 2.105 MeV.

The choice of the representation of the fission spectrum may not be so important for activation reactions with low thresholds, but it becomes important when reactions with very high threshold (say about 10 MeV) are considered.

As can be seen from table 1 the different representations of the ^{235}U fission neutron spectrum give clearly different results for reactions with very high threshold energy. The Euratom Working Group on Reactor Dosimetry noted that the fission neutron spectrum in the energy region above 8 MeV is only known with an accuracy of the order of 25%.

For the application of reactions with high thresholds and for the prediction of helium production by (n,α) reactions the knowledge of the fission neutron spectrum should be improved.

A comparison of the ^{235}U fission neutron spectrum was reported at the Specialists Meeting on Inelastic Scattering and Fission Neutron Spectra |Ar77|, which was sponsored by the Joint Euratom Nuclear Data and Reactor Physics Committee.
The meeting was held at Harwell, April 14-16, 1975, and the proceedings were issued in January 1977. These specialists recommended a Watt spectrum of the type:

$$N(E) = \exp(-AE) \cdot \sinh\sqrt{BE}$$

where A and B are constants defining the shape; and $\bar{E} = (1.5+0.25B/A)/A$.
The correction of finite sample size effect has been shown to be important in some cases, having the overall effect of increasing the average fission neutron energy E. From the proceedings we quote:
"An overall preference for a Watt distribution formalism was found, and it is recommended that a Watt, as opposed to a Maxwell, formalism description be adopted until such time as a better overall description is available. That is, a Watt formalism should be adopted for describing the fission neutron energy range from ~0.5 to 15 MeV.
For ^{235}U, the recommended Watt formalisms A and B parameters are A = 1.0123±0.011 and B = 2.1893±0.1552.
This gives an estimated E value of 2.016 MeV, as compared to the ENDF/B-IV evaluation $\bar{E}$ estimate of 1.895 MeV ... . It is reasonable to consider that the estimated value for $\bar{E}$ is reliable to better than 2-3%.."

At the International Specialists Symposium on Neutron Standard and Applications, held at the N.B.S., March 28-31, 1977, L. Stewart and C.M. Eisenhauer |St77| considered these results and also recent data on ^{252}Cf, and concluded that the Watt distribution should be the recommended parametrization for all important isotopes on the ENDF/B-V file.
They also concluded that the fission spectra shape is considered to be well determined over the range of emitted neutron energies from about 1 to 8 MeV. Below 1 MeV, some experimentalists see a large excess of neutrons over the Watt or the Maxwellian shape, while above 8 MeV the statistical errors are often large due to the extremely low flux density in that region.

Appendix 3: Quality of integral cross section data

Integral experiments to determine σ_o (the 2200 m/s value), I (the resonance integral) and $\langle\sigma\rangle^f$ (the cross section averaged over the fission neutron spectrum) have been performed by experienced people in recognized laboratories. The values for σ_o, I and $\langle\sigma\rangle^f$ which can be derived from the ENDF/B-IV dosimetry file |Ma75,2|, have been compared in tables 2, 3, 4 and 5 with evaluated or experimental data in recent compilations.

For the fission neutron spectra of ^{235}U and ^{252}Cf the NBS evaluations of Grundl and Eisenhauer |Gr75|, |Gr77| were used.

The quality of the comparison can be based on three aspects :

- the uncertainty in the reported values,
- the discrepancy between measured and calculated cross section values, and,
- the consistency between measured and calculated values.

As a measure for the uncertainty in the experimental cross section value we take the fractional error (denoted by σ) as stated by the experimenter.

As a measure of the discrepancy one can take the absolute value of the fractional difference (denoted by Δ) between measured value and the value calculated from the evaluated cross section file.

Thus $\Delta = \left|\frac{\langle\sigma m\rangle - \langle\sigma_c\rangle}{\langle\sigma m\rangle}\right|$. Instead of looking at the difference Δ, one often considers the ration $\langle\sigma_m\rangle/\langle\sigma_c\rangle$.

As a measure of the consistency between the measured value and the calculated value one can take the ratio of the fractional difference and its stated fractional error v.

The following indications are used in the tables :

category	uncertainty	discrepancy	consistency
++	$0 < v < 2\%$	$0 < \Delta < 2\%$	$0 < \Delta/v < 1$
+	$2\% < v < 4\%$	$2\% < \Delta < 4\%$	$1 < \Delta/v < 2$
o	$4\% < v < 6\%$	$4\% < \Delta < 6\%$	$2 < \Delta/v < 3$
-	$6\% < v < 8\%$	$6\% < \Delta < 8\%$	$3 < \Delta/v < 4$
--	$8\% < v$	$8\% < \Delta$	$4 < \Delta/v <$

app. 3.

The data for the fission neutorn spectra are taken from recent reviews by Fabry et al |Fa76| and |Fa77|.
The normalization adopted involves a so-called flux transfer, using the $^{239}Pu(n,f)$ reaction and the NBS ^{252}Cf source. This californium source was chosen because of its availability and its well known source strength (error 1.1%). The $^{239}Pu(n,f)$ reaction was chosen because of its relatively flat shape in the energy range of interest and its well known cross section.
It has been concluded by Fabry, McElroy et al |Fa76| that integral cross section data for dosimetry reactions as measured in standard and reference benchmark neutron fields depart from computed ones, not only because of differential energy cross section inadequacies, but also because the spectral shapes characteristic of these benchmarks are usually inaccurate in the energy ranges not covered or poorly covered by differential neutron spectrometry techniques, e.g.:

- below ≈250 keV and above ≈10 MeV for the fission neutron spectra of ^{235}U and ^{252}Cf;
- below ≈10 keV and above ≈2 MeV for ΣΣ, CFRMF, BIG-TEN.

The same authors conclude that even in the well covered energy ranges, the reliability remains questionable, as is presently the case for the ^{235}U fission neutron spectrum between 3 and 6 MeV, and for CFRMF between 100 and 400 keV.
The only benchmark whose spectral shape appears to be accurately established between ≈0.25 and ≈10 MeV is the ^{252}Cf neutron spectrum. The inconsistencies observed for some facilities like CFRMF and BIG-10 are mostly attributed to inaccurate spectra computations resulting from the inadequate ^{235}U fission spectrum, and the inelastic scattering cross section data in ENDF/B-IV. This effect is less pronounced for ΣΣ, because the spectral characterization from ≈10 keV up to ≈2 MeV mostly relies on differential spectrometry measurements and not on computations |20|.
The 1976 Consultants Meeting recommended that efforts should be made to remove inconsistencies between integral measurements and differential evaluations at least as concerns the ^{235}U fission spectrum, the ΣΣ type facilities and the ISNF, and the cross sections for $^{58}Ni(n,p)$, $^{235}U(n,f)$, $^{59}Co(n,\gamma)$, $^{115}In(n,n')$, $^{54}Fe(n,p)$, $^{103}Rh(n,n')$, so as to qualify them as standard spectra and category I reactions respectively.

Appendix 4: Comparison of cross section representations

Table 1: Influence of representation of fission neutron spectrum of ^{235}U on average cross sections

Based on cross sections from the ENDF/B-IV dosimetry file, and data reported by Fabry et al |Fa76| and |Fa77|. Cross section values are given in fm^2 ($=10^{-30}m^2$).

reaction	effective threshold energy (in MeV)	integral measurement σ_m (in fm^2)	ratio σ_c/σ_m		
			Maxwellian <E>=1.97 MeV	NBS-eval. <E>=1.98 MeV	Watt <E>=2.00 MeV
$^{237}Np(n,f)FP$	0.6	131.2	1.006	1.006	1.019
$^{58}Ni(n,p)^{58}Co$	2.8	10.85	0.926	0.936	0.947
$^{54}Fe(n,p)^{54}Mn$	3.1	7.97	0.965	0.975	0.984
$^{27}Al(n,p)^{27}Mg$	4.4	0.386	1.078	1.067	1.062
$^{56}Fe(n,p)^{56}Mn$	6.0	0.1035	1.081	1.017	1.000
$^{59}Co(n,\alpha)^{56}Mn$	6.8	0.0143	1.140	1.035	1.021
$^{27}Al(n,\alpha)^{24}Na$	7.2	0.0705	1.106	0.983	0.970
$^{127}I(n,2n)^{126}I$	10.5	0.105	1.499	1.130	1.094
$^{55}Mn(n,2n)^{54}Mn$	11.6	0.0244	1.426	1.004	0.951
$^{58}Ni(n,2n)^{57}Ni$	≈13.5	5.77×10^{-4}	0.776	0.489	0.440

Table 2: Comparison of 2200 m/s cross section values

Cross section values are expressed in units of 100 fm^2 (in $10^{-28}m^2$)

reaction	compilation value, σ_m			uncertainty (in %)		calculated value, σ_c ENDF/B-IV |Zij77|	σ_c/σ_m	discrepancy	consistency Δ/v
	IAEA-TR-156 |Sh74|	BNL-325 |Mu73|	BIGHAM |Bi76|						
$^{6}Li(n,\alpha)^{3}H$		940±4		0.4	++	943.7	1.005	++	+
$^{10}B(n,\alpha)^{7}Li$		3837±9		0.2	++	3851	1.004	++	+
$^{23}Na(n,\gamma)^{24}Na$	0.528±0.005	0.530±0.005		0.9	++	0.5360	1.014	++	+
$^{45}Sc(n,\gamma)^{46}Sc$	25±2	**26.5** ±1.0		3.7	+	26.47	1.011	++	o
$^{58}Fe(n,\gamma)^{59}Fe$	1.14 ±0.05	1.15±0.02		1.7	++	1.186	1.033	+	+
$^{59}Co(n,\gamma)^{60}Co$	37.5 ±0.2	37.2 ±0.2		0.5	++	37.39	1.002	++	++
$^{63}Cu(n,\gamma)^{64}Cu$	4.4 ±0.2	4.5 ±0.1		2.2	+	4.513	1.008	++	++
$^{115}In(n,\gamma)^{116}In^{m}$	161±5	157 ±15		9.6	--	170.2	1.060	o	++
$^{197}Au(n,\gamma)^{198}Au$	98.8 ±0.3	98.8 ±0.3	98.7 0.2	0.2	++	99.70	1.010	++	--
$^{232}Th(n,\gamma)^{233}Th$	7.4 ±0.1	7.40±0.08		1.1	++	7.396	1.000	++	++
$^{235}U(n,f)FP$	580 ±2	582.2±1.3	576.9 3.4	0.6	++	574.4	0.989	++	+
$^{237}Np(n,f)FP$		0.019±0.003		15.8	--	0.01610	0.848	--	++
$^{238}U(n,\gamma)^{239}U$	2.720±0.025	2.70 ±0.02		0.7	++	2.716	1.005	++	++
$^{239}Pu(n,f)FP$	742 ±3	742.5±3.0	742.8 4.4	0.6	++	785.3	1.059	o	--

Table 3: Comparison of cross sections, averaged over a 1/E neutron spectrum

Values of resonance integrals refer to a cadmium cut-off equal to 0.5 eV, and are expressed in units of 100 fm^2 ($10^{-28} m^2$).

reaction	compilation value, σ_m		uncertainty		calculated value, σ_c ENDF/B-IV |Ma75,2|, |Mu73|	σ_c/σ_m	discrepancy	consistency Δ/v
	IAEA-TR-156 |A174|	BNL-325 |Mu73|	(in %)					
$^{6}Li(n,total\ He)$	-	-	-		425.87	-		
$^{10}B(n,total\ He)$	-	1722	0.3	++	1722.17	1.000	++	++
$^{23}Na(n,\gamma)^{24}Na$	0.31	0.311	3.2	+	0.346	1.113	--	-
$^{45}Se(n,\gamma)^{46}Sc$	11	11.3	8.8	-	11.29	0.999	++	++
$^{58}Fe(n,\gamma)^{59}Fe$	1.2	1.19	5.9	o	1.58	1.328	--	--
$^{59}Co(n,\gamma)^{60}Co$	75.0	75.5	2.0	++	76.67	1.015	++	++
$^{63}Cu(n,\gamma)^{64}Cu$	5.0	4.9	6.2	-	5.55	1.133	--	o
$^{115}In(n,\gamma)^{116}In^{m}$	2600	3300	3.0	+	3242.74	0.983	++	+
$^{197}Au(n,\gamma)^{198}Au$	1550	1560	2.6	+	1564.70	1.003	++	++
$^{232}Th(n,\gamma)^{233}Th$	82	85	3.5	+	85.58	1.007	++	++
$^{235}U(n,f)FP$	275	275	1.8	++	282.00	1.025	+	+
$^{238}U(n,\gamma)^{239}U$	280	275	1.8	++	277.53	1.009	++	++
$^{239}Pu(n,f)FP$	310	301	3.3	+	303.90	1.010	++	++

Table 4: Comparison of cross sections, averaged over the fission neutron spectrum of ^{235}U

Cross section values are expressed in units of $fm^2 (=10^{-30} m^2)$. Calculated values refer to the ENDF/B-IV dosimetry file and the NBS spectrum evaluation. Table is based on data reported by Fabry et al. |Fa76|, |Fa77| and |Fa78|.

reaction	effective threshold (in MeV)	integral measurement σ_m (in fm^2)	uncertainty (in %)		calculated value σ_c (in fm^2)	σ_c/σ_m	discrepancy	consistency Δ/v
$^{115}In(n,\gamma)^{116}In^m$	-	13.45	4.5	o	13.59	1.010	++	++
$^{197}Au(n,\gamma)^{198}Au$	-	8.35	6.0	o	8.46	1.013	++	++
$^{63}Cu(n,\gamma)^{64}Cu$	-	0.930	15.0	--	1.099	1.182	--	+
$^{235}U(n,f)FP$	-	120.3	2.5	+	124.1	1.032	+	+
$^{239}Pu(n,f)FP$	-	181.1	3.3	+	178.1	0.983	++	++
$^{237}Np(n,f)$	0.6	131.2	3.8	+	132.0	1.006	++	++
$^{103}Rh(n,n')^{103}Rh^m$	0.8	73.3	5.2	o	-	-		
$^{115}In(n,n')^{115}In^m$	1.2	18.9	4.2	o	18.17 a) 17.28 b)	0.961 0.914	+ --	++ o
$^{232}Th(n,f)FP$	1.4	8.1	6.7	-	6.90	0.852	--	o
$^{238}U(n,f)FP$	1.5	30.5	3.3	+	29.58	0.970	+	++
$^{47}Ti(n,p)^{47}Sc$	2.2	1.90	7.4	-	2.14 2.138 c)	1.126 1.125	-- --	+ +
$^{31}P(n,p)^{31}Si$	2.4	3.55	7.6	-	3.245 d)	0.914	-	+
$^{58}Ni(n,p)^{58}Co$	2.8	10.85	5.0	o	10.16	0.936	-	+
$^{64}Zn(n,p)^{64}Cu$	2.8	2.99	5.4	o	-	-		
$^{32}S(n,p)^{32}P$	2.9	6.68	5.5	o	6.41	0.960	+	++
$^{54}Fe(n,p)^{54}Mn$	3.1	7.97	6.1	-	7.77	0.975	+	++
$Ti(n,x)^{46}Sc$	3.9	1.18	6.4	-	0.999 1.088 c)	0.847 0.922	-- -	o o
$^{27}Al(n,p)^{27}Mg$	4.4	0.386	6.5	-	0.412	1.067	-	o
$^{56}Fe(n,p)^{56}Mn$	6.0	0.1035	7.2	-	0.1053	1.017	++	++
$^{59}Co(n,\alpha)^{56}Mn$	6.8	0.0143	7.0	-	0.0148	1.035	+	++
$^{63}Cu(n,\alpha)^{60}Co$	6.8	0.0500	11.2	--	0.0352	0.704	--	o
$^{24}Mg(n,p)^{24}Na$	6.8	0.148	5.5	o	0.1518 d)	1.026	+	++
$^{27}Al(n,\alpha)^{24}Na$	7.2	0.0705	5.7	o	0.0693	0.983	++	++
$^{48}Ti(n,p)^{48}Sc$	7.6	0.0300	6.0	o	0.0173 0.0303 c)	0.577 1.010	-- ++	-- ++
$^{93}Nb(n,2n)^{92}Nb^m$	10.2	0.0475	6.7	-	-	-		
$^{127}I(n,2n)^{126}I$	10.5	0.105	6.2	-	0.1186	1.130	--	o
$^{55}Mn(n,2n)^{54}Mn$	11.6	0.0244	6.1	-	0.0245	1.004	++	++
$^{63}Cu(n,2n)^{62}Cu$	12.4	0.0122	9.8	--	0.00915	0.750	--	o
$^{90}Zr(n,2n)^{89}Zr$	≈13	0.0247	6.9	-	0.008714	0.353	--	--
$^{58}Ni(n,2n)^{57}Ni$	≈13.5	5.77×10^{-4}	5.4	o	2.82×10^{-4}	0.489	--	--

a) Magurno |Ma75/2| reports a calculated value of 16.68 fm^2, based on a branching ratio of 50% for the 336 keV gamma radiation. If this branching ratio is taken as 45.9% (see |Ha74|), then the value becomes $16.68\times(50/45.9) = 18.17$ fm^2.

b) Based on a recent evaluation by D.L. Smith |Sm76| using a Maxwellian spectrum with <E> = 1.98 MeV.

c) Based on a recent evaluation by C. Philis et al. |Ph77|.

d) Cross section data not present in ENDF/B-IV dosimetry file; listed value has been taken from SAND-II cross section file.

Table 5: Comparison of cross sections, averaged over the fission neutron spectrum of ^{252}Cf

Cross section values are expressed in units of $fm^2 (=10^{-30} m^2)$. Calculated values refer to the ENDF/B-IV dosimetry file and the NBS spectrum evaluation.
Table is based on data reported by Fabry et al |Fa76|, |Fa77| and |Fa78|.

reaction	effective threshold (in MeV) a)	integral measurement σ_m (in fm^2)	uncertainty (in %)		calculated value σ_c (in fm^2)	σ_c/σ_m	dis-cre-pancy	consis-tency Δ/v
$^{115}In(n,\gamma)^{116}In^m$		12.53	3.4	+	13.03	1.040	+	+
$^{197}Au(n,\gamma)^{198}Au$		7.99	3.6	+	7.99	1.000	++	++
$^{235}U(n,f)FP$		120.3	2.5	+	124.1	1.033	+	+
$^{239}Pu(n,f)FP$		180.4	2.5	+	178.9	0.992	++	++
$^{237}Np(n,f)FP$	0.6	133.2	2.8	+	135.1	1.014	++	++
$^{103}Rh(n,n')^{103}Rh^m$	0.8	75.7	7.0	–	–	–		
$^{115}In(n,n')^{115}In^m$	1.2	19.8	2.5	+	17.55 b)	0.886 b)	--	--
$^{238}U(n,f)FP$	1.5	32.0	2.8	+	31.54	0.986	++	++
$^{47}Ti(n,p)^{47}Sc$	2.2	1.89	2.1	+	2.384	1.261	--	--
					2.422 c)	1.281 c)	--	--
$^{58}Ni(n,p)^{58}Co$	2.8	11.8	2.5	+	11.50	0.975	+	++
$^{54}Fe(n,p)^{54}Mn$	3.1	8.46	2.4	+	8.91	1.053	o	o
$^{46}Ti(n,p)^{46}Sc$	3.9	1.38	2.2	+	1.252	0.907	–	--
					1.381 c)	1.001 c)	++	++
$^{27}Al(n,p)^{27}Mg$	4.4	0.51	9.8	--	0.514	1.008	++	++
$^{56}Fe(n,p)^{56}Mn$	6.0	0.145	2.4	+	0.1475	1.017	++	++
$^{27}Al(n,\alpha)^{24}Na$	7.2	0.1006	2.2	+	0.1059	1.053	–	o
$^{48}Ti(n,p)^{48}Sc$	7.6	0.042	2.4	+	0.265	0.630	--	--
					0.0446 c)	1.062 c)	–	o
$^{55}Mn(n,2n)^{54}Mn$	11.6	0.058	10.3	--	0.0528	0.910	–	++
$^{59}Co(n,2n)^{58}Co$		0.057	10.5	--	0.0379	0.665	--	–
$^{63}Cu(n,2n)^{62}Cu$	12.4	0.030	10.0	--	0.02415	0.715	--	--

a) Threshold values are valid for a ^{235}U fission neutron spectrum.
b) Based on a recent evaluation by D.L. Smith |Sm76|.
c) Based on a recent evaluation by C. Philis et al |Ph77|.

Appendix 5: Cross sections, averaged over a fission spectrum

Values refer to various representations of the fission spectrum of ^{235}U, as defined in appendix 2. All values are expressed in the unit cm^{+2}.

reaction	Watt $X_1(E)$	Cranberg $X_2(E)$	Leachman $X_3(E)$	Grundl $X_6(E)$	Grundl (mod.) $X_3(E)$
LI6(N,A)H3	4.796E-25	4.785E-25	4.871E-25	4.864E-25	4.899E-25
B10(N,A)	5.039E-25	5.036E-25	5.150E-25	5.128E-25	5.101E-25
NA23(N,G)NA24	2.849E-28	2.854E-28	2.948E-28	2.921E-28	2.876E-28
AL27(N,A)NA24	6.844E-28	6.254E-28	7.095E-28	7.801E-28	6.935E-28
AL27(N,P)MG27	4.101E-27	3.929E-27	3.928E-27	4.158E-27	4.122E-27
S32(N,P)P32	6.505E-26	6.391E-26	6.134E-26	6.332E-26	6.409E-26
SC45(N,G)SC46	5.716E-27	5.737E-27	5.983E-27	5.903E-27	5.832E-27
TI47(N,NP)SC46	3.172E-30	2.503E-30	4.950E-30	5.969E-30	3.603E-30
TI48(N,NP)SC47	1.820E-30	1.475E-30	2.623E-30	3.117E-30	2.001E-30
FE54(N,P)MN54	7.847E-26	7.668E-26	7.407E-26	7.689E-26	7.773E-26
MN55(N,2N)MN54	2.321E-28	1.947E-28	2.997E-28	3.485E-28	2.450E-28
FE56(N,P)MN56	1.035E-27	9.647E-28	1.033E-27	1.120E-27	1.053E-27
FE58(N,G)FE59	1.676E-27	1.678E-27	1.713E-27	1.702E-27	1.692E-27
NI58(N,2N)NI57	2.540E-30	2.039E-30	3.752E-30	4.478E-30	2.819E-30
NI58(N,P)CO58	1.028E-25	1.008E-25	9.724E-26	1.006E-25	1.017E-25
CO59(N,A)MN56	1.457E-28	1.340E-28	1.493E-28	1.634E-28	1.480E-28
CO59(N,2N)CO58	1.624E-28	1.356E-28	2.130E-28	2.485E-28	1.723E-28
CO59(N,G)CO60	6.382E-27	6.404E-27	6.587E-27	6.519E-27	6.463E-27
NI60(N,P)CO60	2.443E-27	2.289E-27	2.414E-27	2.603E-27	2.478E-27
CU63(N,A)CO60	3.472E-28	3.198E-28	3.537E-28	3.865E-28	3.523E-28
CU63(N,G)CU64	1.082E-26	1.085E-26	1.118E-26	1.107E-26	1.098E-26
CU65(N,2N)CU64	2.976E-28	2.506E-28	3.805E-28	4.415E-28	3.132E-28
IN115(N,G)IN116	1.350E-25	1.356E-25	1.385E-25	1.371E-25	1.359E-25
I127(N,2N)I126	1.149E-27	9.900E-28	1.377E-27	1.575E-27	1.186E-27
AU197(N,G)AU198	8.306E-26	8.339E-26	8.658E-26	8.546E-26	8.456E-26
TH232(N,F)F.P.	7.026E-26	6.958E-26	6.726E-26	6.863E-26	6.901E-26
TH232(N,G)TH233	1.019E-25	1.024E-25	1.055E-25	1.043E-25	1.033E-25
U235(N,F)FP	1.241E-24	1.241E-24	1.243E-24	1.243E-24	1.241E-24
NP237(N,F)F.P.	1.337E-24	1.335E-24	1.313E-24	1.321E-24	1.320E-24
U238(N,F)FP	3.016E-25	2.994E-25	2.889E-25	2.940E-25	2.959E-25
U238(N,G)U239	7.430E-26	7.466E-26	7.687E-26	7.594E-26	7.507E-26
PU239(N,F)FP	1.786E-24	1.785E-24	1.780E-24	1.782E-24	1.781E-24
MN55(N,G)MN56	3.560E-27	3.570E-27	3.705E-27	3.663E-27	3.598E-27
AG109(N,G)AG110M	1.151E-26	1.153E-26	1.184E-26	1.174E-26	1.165E-26
MG24(N,P)NA24	1.498E-27	1.377E-27	1.533E-27	1.678E-27	1.518E-27
P31(N,P)SI31	3.301E-26	3.252E-26	3.115E-26	3.205E-26	3.245E-26
CU63(N,2N)CU62	8.464E-29	6.946E-29	1.169E-28	1.378E-28	9.151E-29
ZR90(N,2N)ZR89	7.953E-29	6.450E-29	1.138E-28	1.350E-28	8.714E-29
TA181(N,G)TA182	1.036E-25	1.040E-25	1.084E-25	1.068E-25	1.056E-25
L64ZN(N,P)64CU	4.294E-26	4.209E-26	4.053E-26	4.193E-26	4.238E-26
L64ZN(N,2N)63ZN	1.657E-29	1.331E-29	2.446E-29	2.919E-29	1.839E-29
L90ZR(N,P)90Y	3.567E-28	3.336E-28	3.552E-28	3.839E-28	3.616E-28
L103RH(N,N)103RH	7.135E-25	7.109E-25	6.947E-25	7.015E-25	7.039E-25
TH232(N,2N)231TH	1.503E-26	1.374E-26	1.550E-26	1.703E-26	1.518E-26
IN115(N,N)IN115M	1.768E-25	1.759E-25	1.698E-25	1.722E-25	1.734E-25
AM241(N,F)FP	1.217E-24	1.213E-24	1.183E-24	1.195E-24	1.197E-24
TI46(N,P)SC46	1.056E-26	1.011E-26	1.011E-26	1.071E-26	1.064E-26
TI47(N,P)SC47	2.141E-26	2.105E-26	2.029E-26	2.091E-26	2.111E-26
TI48(N,P)SC48	2.637E-28	2.420E-28	2.721E-28	2.985E-28	2.680E-28

Appendix 6: Gamma-ray spectrometry standards listed by radionuclide

The choice is based on a long half-life, and a good knowledge of gamma-ray energies and gamma-ray emission probabilities.
Data are taken from |MED78|, unless otherwise indicated.

	nuclide	γ-ray energy (in keV)	γ-ray emission probability (in %)	half-life		remark
	^{22}Na	1274.540(20)	99.94(2)	2.602(2)	a	
+	^{54}Mn	834.827(21)	99.9760(20)	312.5(5)	d	
+	^{57}Co	14.4127(4)	9.54(13)	271.5(5)	d	(c)
+		122.063(3)	85.59(19)			
+		136.476(3)	10.61(18)			
+++	^{60}Co	1173.210(10)	99.900(20)	5.271(1)	a	
++		1332.470(10)	99.9824(5)			
	^{65}Zn	1115.52(3)	50.4(3)	243.97(8)	d	(b),(c)
	^{88}Y	898.020(20)	94.6(5)	106.64(8)	d	(b)
		1836.040(20)	99.35(3)			
+	$^{110}Ag^{m}$	657.749(10)	94.7(10)	249.78(4)	d	(c)
+		706.670(13)	16.74(12)			
+		763.928(13)	22.36(23)			
+		884.667(13)	72.9(8)			
+		937.478(13)	34.3(4)			
+		1384.270(13)	24.35(25)			
+		1505.001(21)	13.11(14)			
++	^{133}Ba	53.155(16)	2.17(4)	10.74(5)	a	
+		79.621(11)	2.66(8)			
+		80.997(5)	33.5(5)			
+		276.397(12)	7.09(13)			
+		302.851(15)	18.40(20)			
+		356.005(17)	62.1(7)			
+		383.851(15)	8.91(10)			
+	^{137}Cs	661.645(9)	85.0(5)	30.0(2)	a	
++	^{139}Ce	165.853(7)	79.94(13)	137.66(2)	d	
+++	^{152}Eu	121.7824(11)	28.37(30)	13.5(1)	a	(c),(d)
++		244.6989(11)	7.51(7)			
++		344.275(4)	26.58(24)			
++		411.115(5)	2.234(18)			
++		443.983(7)	3.121(24)			
++		778.910(10)	12.96(10)			
++		964.131(9)	14.62(8)			
++		1085.914(13)	10.16(8)			
++		1112.116(17)	13.56(8)			
++		1408.011(14)	20.85(12)			
++	^{182}Ta	100.1064(3)	14.23(42)	114.41(2)	d	(b),(c)
++		113.6670(12)	1.87(6)			
++		116.4149(17)	0.445(15)			
++		152.4281(14)	6.95(9)			
++		156.3817(12)	2.63(5)			
++		179.3904(18)	3.09(4)			
++		198.3477(22)	1.44(2)			
++		222.1010(20)	7.50(10)			
++		229.316(3)	3.64(5)			
++		264.071(6)	3.62(6)			
++		1121.28(3)	35.30(32)			
++		1189.04(4)	16.44(15)			
++		1221.418(25)	27.17(25)			
++		1230.97(3)	11.58(11)			

Appendix 6 (continued):

	nuclide	γ-ray energy (in keV)	γ-ray emission probability (in %)	half-life	remark
+	^{203}Hg	279.190(5)	81.5(8)	46.60(2) d	
+	^{241}Am	59.5370(10)	36.0(3)	432.0(2) a	(b),(c)

(b) emission probability values taken from |PTB79|

(c) half-life values taken from |PTB79|

(d) emission probability values taken from |De79|

Appendix 7: Characteristics of the neutron spectra.

HFR SPECTRUM.

NEUTRON FLUX DENSITIES FOR ABBNGROUPS

GROUP.	ENERGY REGION (IN MEV)	GROUP FLUX DENSITY (M-2.S-1)	PHI(U) REL.
1	1.050E+01... 6.500E+00	4.121E+15	1.198E-02
2	6.500E+00... 4.000E+00	2.043E+16	5.869E-02
3	4.000E+00... 2.500E+00	4.611E+16	1.368E-01
4	2.500E+00... 1.400E+00	7.911E+16	1.903E-01
5	1.400E+00... 8.000E-01	7.095E+16	1.768E-01
6	8.000E-01... 4.000E-01	7.476E+16	1.504E-01
7	4.000E-01... 2.000E-01	5.617E+16	1.130E-01
8	2.000E-01... 1.000E-01	4.363E+16	8.779E-02
9	1.000E-01... 4.650E-02	3.451E+16	6.286E-02
10	4.650E-02... 2.150E-02	2.458E+16	4.443E-02
11	2.150E-02... 1.000E-02	2.072E+16	3.775E-02
12	1.000E-02... 4.650E-03	1.948E+16	3.548E-02
13	4.650E-03... 2.150E-03	1.856E+16	3.356E-02
14	2.150E-03... 1.000E-03	1.806E+16	3.290E-02
15	1.000E-03... 4.650E-04	1.781E+16	3.244E-02
16	4.650E-04... 2.150E-04	1.767E+16	3.195E-02
17	2.150E-04... 1.000E-04	1.729E+16	3.151E-02
18	1.000E-04... 4.650E-05	1.708E+16	3.110E-02
19	4.650E-05... 2.150E-05	1.694E+16	3.062E-02
20	2.150E-05... 1.000E-05	1.655E+16	3.015E-02
21	1.000E-05... 4.650E-06	1.640E+16	2.987E-02
22	4.650E-06... 2.150E-06	1.655E+16	2.993E-02
23	2.150E-06... 1.000E-06	1.647E+16	3.000E-02
24	1.000E-06... 4.650E-07	1.649E+16	3.004E-02
25	4.650E-07... 2.150E-07	1.660E+16	3.002E-02

TOTAL FOR 25 ABBN GROUPS 7.171E+17

NEUTRON FLUX DENSITIES FOR SPECIAL ENERGY GROUPS

E > 10.5 MEV	:	2.663E+14
E > 1.0 MEV	:	1.934E+17
E > 0.1 MEV	:	3.953E+17
E < 0.215 EV	:	1.087E+17
T O T A L	=	8.261E+17

SPECTRUM CHARACTERISTICS

AVERAGE ENERGY = 6.966E-01 MEV PHI(NI) = 2.419E+17 M-2.S-1
AVARAGE SPEED = 1.700E+04 M.S-1 PHI(FE) = 2.375E+17 M-2.S-1
AVERAGE LETHARGY= 7.794E+00 PHI(CO) = 1.433E+17 M-2.S-1

DAMAGE TO ACTIVATION RATIO (D A R).

	GRAPHITE	STEEL	ALUMINIUM
NI58(N,P)CO58	1.65E+00	1.30E+00	1.44E+00
FE54(N,P)MN54	1.64E+00	1.29E+00	1.43E+00

CTR SPECTRUM (TOKAMAK) REF |DI79|

NEUTRON FLUX DENSITIES FOR ABBNGROUPS

GROUP.	ENERGY REGION (IN MEV)	GROUP FLUX DENSITY (M-2.S-1)	PHI(U) REL.
1	1.050E+01... 6.500E+00	2.306E+02	6.376E-02
2	6.500E+00... 4.000E+00	2.553E+02	6.972E-02
3	4.000E+00... 2.500E+00	3.223E+02	9.093E-02
4	2.500E+00... 1.400E+00	4.570E+02	1.045E-01
5	1.400E+00... 8.000E-01	7.320E+02	1.734E-01
6	8.000E-01... 4.000E-01	1.150E+03	2.200E-01
7	4.000E-01... 2.000E-01	1.131E+03	2.164E-01
8	2.000E-01... 1.000E-01	8.790E+02	1.681E-01
9	1.000E-01... 4.650E-02	8.052E+02	1.394E-01
10	4.650E-02... 2.150E-02	6.436E+02	1.106E-01
11	2.150E-02... 1.000E-02	4.400E+02	7.622E-02
12	1.000E-02... 4.650E-03	2.278E+02	3.944E-02
13	4.650E-03... 2.150E-03	1.428E+02	2.454E-02
14	2.150E-03... 1.000E-03	6.555E+01	1.135E-02
15	1.000E-03... 4.650E-04	8.124E+00	1.407E-03
16	4.650E-04... 2.150E-04	3.485E+01	5.990E-03
17	2.150E-04... 1.000E-04	1.290E+01	2.235E-03
18	1.000E-04... 4.650E-05	3.504E+00	6.068E-04
19	4.650E-05... 2.150E-05	2.500-101	4.297-105
20	2.150E-05... 1.000E-05	1.150-101	1.992-105
21	1.000E-05... 4.650E-06	5.350-102	9.264-106
22	4.650E-06... 2.150E-06	2.500-102	4.297-106
23	2.150E-06... 1.000E-06	1.150-102	1.992-106
24	1.000E-06... 4.650E-07	5.350-103	9.264-107
25	4.650E-07... 2.150E-07	2.500-103	4.297-107

TOTAL FOR 25 ABBN GROUPS 7.542E+03

NEUTRON FLUX DENSITIES FOR SPECIAL ENERGY GROUPS

E > 10.5 MEV	:	2.535E+03
E > 1.0 MEV	:	4.253E+03
E > 0.1 MEV	:	5.157E+03
E < 0.215 EV	:	2.149-103
T O T A L	=	1.008E+04

SPECTRUM CHARACTERISTICS

AVERAGE ENERGY = 4.293E+00 MEV PHI(NI) = 1.259E+04 M-2.S-1
AVARAGE SPEED = 4.841E+06 M.S-1 PHI(FE) = 1.495E+04 M-2.S-1
AVERAGE LETHARGY= 2.752E+00 PHI(CO) = 2.390E+01 M-2.S-1

DAMAGE TO ACTIVATION RATIO (D A R).

	GRAPHITE	STEEL	ALUMINIUM
NI58(N,P)CO58	6.20E-01	7.95E-01	6.07E-01
FE54(N,P)MN54	5.11E-01	6.55E-01	5.00E-01

Appendix 8: Effective threshold energies.

All threshold values are expressed in the unit MeV.
The values for the effective thresholds were calculated using the SAND-II group structure, applying a least squares fit of the response for a step cross section curve to the multigroup response curve.
The cross section data for the threshold reactions were taken from the DOSCROS77 library |Zij77|.
The spectra used have been mentioned on page 6.

reaction	CTR	^{252}Cf	^{235}U	CFRMF	ΣΣ	MTR
^{24}Mg(n,p)^{24}Na	7.79	7.10	6.60	6.60	6.60	7.10
^{27}Al(n,α)^{24}Na	7.79	7.30	7.20	7.30	7.20	7.30
^{27}Al(n,p)^{27}Mg	6.07	4.50	4.40	4.50	4.50	4.50
^{31}P (n,p)^{31}Si	2.23	2.40	2.40	2.40	2.40	2.40
^{32}S (n,p)^{32}P	2.87	2.70	2.70	2.70	2.70	2.70
^{46}Ti(n,p)^{46}Sc	6.07	4.50	4.40	4.50	4.50	4.40
^{47}Ti(n,np)^{46}Sc	13.5	14.5	14.4	14.5	14.5	14.5
^{47}Ti(n,p)^{47}Sc	3.68	2.30	2.30	2.30	2.20	2.30
^{48}Ti(n,np)^{47}Sc	13.5	12.9	12.8	12.9	12.8	12.8
^{48}Ti(n,p)^{48}Sc	10.0	7.00	6.80	6.90	6.80	7.00
^{55}Mn(n,2n)^{54}Mn	12.0	11.5	11.4	11.4	11.4	11.4
^{54}Fe(n,p)^{54}Mn	2.87	3.10	3.00	2.90	2.90	2.90
^{56}Fe(n,p)^{56}Mn	7.79	6.10	6.00	6.10	6.00	6.10
^{59}Co(n,α)^{56}Mn	10.0	7.00	6.80	6.90	6.80	6.90
^{59}Co(n,2n)^{58}Co	12.0	11.7	11.6	11.7	11.6	11.6
^{58}Ni(n,p)^{58}Co	2.87	2.80	2.70	2.70	2.70	2.70
^{60}Ni(n,2n)^{60}Ni	13.5	13.4	13.4	13.4	13.4	13.4
^{60}Ni(n,p)^{60}Co	7.79	5.90	5.80	5.90	5.80	5.90
^{63}Cu(n,α)^{60}Co	7.79	6.70	6.60	6.60	6.60	6.70
^{63}Cu(n,2n)^{62}Cu	13.5	12.5	12.5	12.5	12.5	12.5
^{65}Cu(n,2n)^{64}Cu	12.0	11.3	11.2	11.3	11.2	11.3
^{64}Zn(n,p)^{64}Cu	2.87	2.80	2.70	2.70	2.60	2.70
^{64}Zn(n,2n)^{63}Zn	13.5	13.5	13.4	13.5	13.5	13.4
^{90}Zr(n,p)^{90}Y	10.0	6.00	5.80	6.00	5.90	5.90
^{90}Zr(n,2n)^{89}Zr	13.5	13.0	13.0	13.0	13.0	13.0
^{103}Rh(n,n')^{103}Rh	0.500	0.760	0.760	0.630	0.630	0.690
^{115}In(n,n')^{115}In^{m}	0.823	1.30	1.30	1.20	1.20	1.30
^{127}I (n,2n)^{126}I	10.0	10.2	10.2	10.2	10.2	10.2
^{232}Th(n,2n)^{231}Th	7.79	7.30	7.30	7.30	7.30	7.30
^{232}Th(n,f)f.p.	6.07	1.40	1.40	1.40	1.40	1.40
^{238}U (n,f)f.p.	1.74	1.50	1.50	1.50	1.50	1.50
^{237}Np(n,f)f.p.	0.500	0.575	0.575	0.550	0.550	0.575
^{241}Am(n,f)f.p.	0.823	0.920	0.920	0.840	0.840	-

Remark:
Since the effective threshold is not a good parameter for the characterization of the energy dependent cross section functions, and since the concept is not used in practical applications, this appendix is included here only to give a rough indication for the start of the response of a threshold neutron detector.
If one wishes to characterize the response range with a single parameter, the median energy of the response seems a more useful parameter. Moreover the median energy of the response can also be defined for non-threshold reactions. Median energy values are presented under the heading "response data" at the separate reactions in the main text.

Part II

CONTENTS : Page:

List of symbols for physical quantities:

A_r	relative atomic mass of an element
$E(\beta)$	beta ray energy
$E(\gamma)$	gamma ray energy
$E(\gamma\pm)$	annihilation radiation
$\langle E \rangle$	mean neutron energy for a neutron spectrum
g	Westcott g-factor
I	resonance integral cross section
I'	resonance integral cross section minus 1/v contribution
I.T.	isomeric transition
N_m	number of atoms per unit mass
N_v	number of atoms per unit volume
P_β	beta ray emission probability
P_γ	gamma ray emission probability
$\Sigma P\beta$	sum of omitted beta ray emission probabilities
$\Sigma P\gamma$	sum of omitted gamma ray emission probabilities
s_o	reduced Westcott s factor
$T_{\frac{1}{2}}$	half-life
$\langle u \rangle$	average lethargy for a neutron spectrum
$\langle v \rangle$	average neutron speed for a neutron spectrum
λ	decay constant
ρ	mass density
σ_o	thermal cross section for E = 0.0253 eV
σ_{act}	activation cross section
σ_c	calculated cross section
$\langle\sigma\rangle_c$	calculated cross section averaged over a fission neutron spectrum
σ_f	fission cross section for E = 0.0253 eV
$\langle\sigma\rangle^f$	cross section averaged over a fission neutron spectrum
σ_m	measured cross section
$\langle\sigma\rangle_m$	measured cross section averaged over a fission neutron spectrum
$\sigma(E)$	energy dependent cross section
$\phi(Co)$	equivalent fission flux density for the reaction $^{59}Co(n,\gamma)^{60}Co$
$\phi(Fe)$	equivalent fission flux density for the reaction $^{54}Fe(n,p)^{54}Mn$
$\phi(Ni)$	equivalent fission flux density for the reaction $^{58}Ni(n,p)^{58}Co$

Preface

This document was prepared within the framework of the activities of the subgroup "Nuclear Data" of the Euratom Working Group on Reactor Dosimetry (EWGRD). This subgroup has the following aims:

a. Preparation of recommendations to the EWGRD to apply certain neutron detection reactions for specified purposes;
b. Preparation of recommendations to the EWGRD to apply particular energy dependent cross section data (from a specific file), so that each laboratory in the European Community uses the same data sets (where necessary parallel to own preferred data sets);
c. Preparation of recommendations to the EWGRD to apply specified non-neutron nuclear data (decay schemes, half-lives);
d. Preparation of recommendation to the EWGRD to apply specified fission yields.

A first document dealing with activation reactions only was presented at the second ASTM-Euratom Symposium on Reactor Dosimetry, held at Palo Alto, 3-7 October 1977. As separate document it was available as report ECN-37 |Zij78|. A revised report (1979 edition) is issued as ECN report simultaneously with this report.
The present document supplements this revised report with the same title, which report constitutes part I dealing with activation reactions.
This part II should be considered as a working document to arrive at a more official recommendation at a later date.
For this reason the title of the document does not refer to a recommendation proper, but to a guide.
It is expected that this guide has to be updated after one or two years, implying an improvement and extension of the nuclear data relevant to reactor irradiation measurements.

Where appropriate this guide gives numerical data from a few preferred information sources which are listed below.

List of preferred general references :

quantity of interest	sources	reference code
relative atomic mass	Holden	Ho79
mass density melting point	Handbook of Physics and Chemistry (59th edition)	We79
level scheme decay data	Nuclear Data Sheets Martin Kocher ENSDF (MEDLIST)	various authors Ma76 Ko77 MED78
cross sections fission yields	ENDF/B-IV Cuninghame Meek and Rider Gilliam et al.	Ma75 Cu77 Me77 Gi78

The principle is followed that where possible each numerical value is referenced.

The uncertainties quoted are those from the original literature sources. Sometimes the following notation by Martin |Ma76| was followed :

3.624(12) means { recommended value 3.624
uncertainty 0.012

The uncertainties quoted in the various references are assumed to be standard deviations (1σ).

In some cases where the decay schemes of product nuclides are rather complex, energy levels and radiation transitions may not have been indicated in all completeness.

As a general rule the decay schemes show only transitions with abundances larger than 1%, while the beta and gamma transitions are only listed when their abundances are larger than 0.1%.

For the case of a radioactive parent (p) feeding a radioactive daughter (d) in a fraction (f) of the parent decays, the ratio of the daughter activity to that of the parent at time (t) is given by

$$\frac{f\,T_{\frac{1}{2}}(p)}{T_{\frac{1}{2}}(p) - T_{\frac{1}{2}}(d)} \left[1 - e^{-(\lambda_d - \lambda_p)t}\right] , \qquad (1)$$

where $T_{\frac{1}{2}}(p)$ and $T_{\frac{1}{2}}(d)$ are the half-lives, and λ_p and λ_d are the decay constants ($\lambda = \ln 2/T_{\frac{1}{2}}$) of the parent and daughter, respectively.

The activity of the daughter is assumed to be zero at time t=0. For cases in which the daughter is short-lived compared with the parent, the parent-daughter activity ratio approaches a constant value with time. For a time large compared with $1/(\lambda_d-\lambda_p)$, Eq. (1) reduces to

$$\frac{f T_{\frac{1}{2}}(p)}{T_{\frac{1}{2}}(p) - T_{\frac{1}{2}}(d)} \quad . \qquad (2)$$

For example, ^{99}Mo decays to $^{99}Tc^m$ (6.02 h) with $T_{\frac{1}{2}}(p) = 66.0(2)$ h, $T_{\frac{1}{2}}(d) = 6.02(3)$ h, and $f = 0.8752(18)$. For large t ($t > 10\ T_{\frac{1}{2}}(d)$ is sufficient here), the ratio of $^{99}Tc^m$ activity to that of ^{99}Mo is (0.8752(18))(1.1004(4)) = 0.9631(20). Thus, to correctly account for all radiations from a ^{99}Mo source, the radiations from $^{99}Tc^m$ (6.02 h) should be multiplied by 0.9631(20) and combined with those from ^{99}Mo.

For (nearly) all detection reactions three figures are presented :

1. A figure showing the cross section as function of energy. These plots are consistent with the cross section library DOSCROS 77 |Zij77|. The energy scale is taken linear for threshold reactions, and logarithmic for radiative capture reactions. The cross section scale is always logarithmic.
2. Two figures showing the energy dependence of the response function which is defined as the integral of the energy dependent reaction cross section and the flux density per unit energy as a function of energy.

   The response function is presented in this report as the response per unit lethargy.

   The energy scale is linear or logarithmic as under 1.

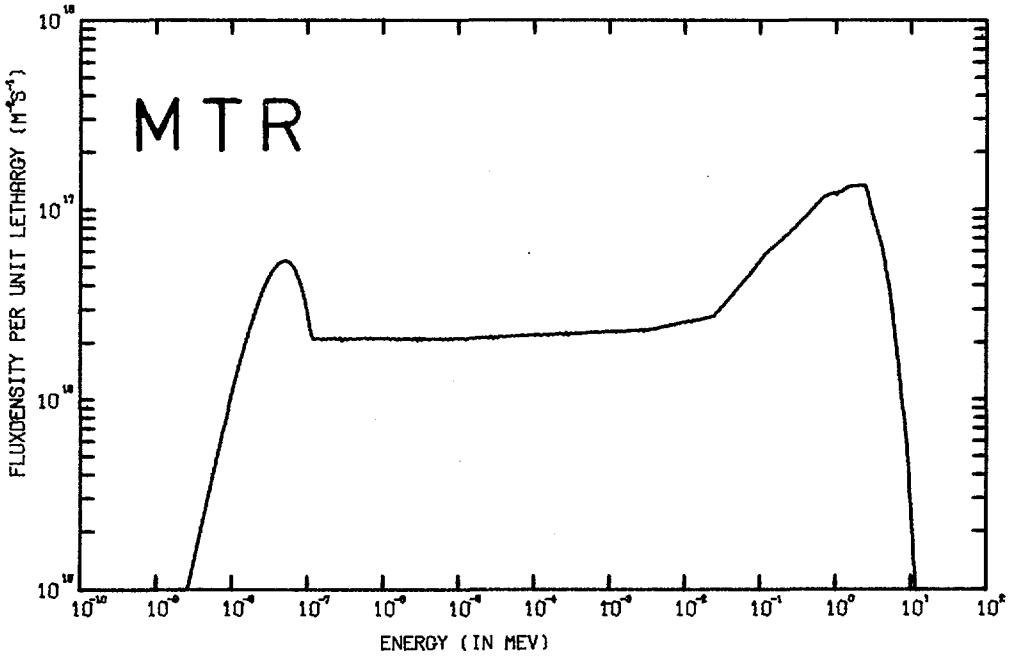
   The response functions have been normalized to unit integral, i.e. $\int \phi(E).\phi_E(E)dE = 1$ or $\int \phi(u).\phi_u(u)\ du = 1$.

   Two response plots are given for the fission reactions under consideration, one for a light water reactor, and one for a CTR TOKAMAK neutron spectrum. The light water neutron spectrum applies to an experiment position in the middle of the fuel region of the High Flux Reactor (HFR) at Petten. The neutron spectrum used has been calculated by means of the diffusion code TEDDI-M for HFR position E5. The high energy region has been smoothed.

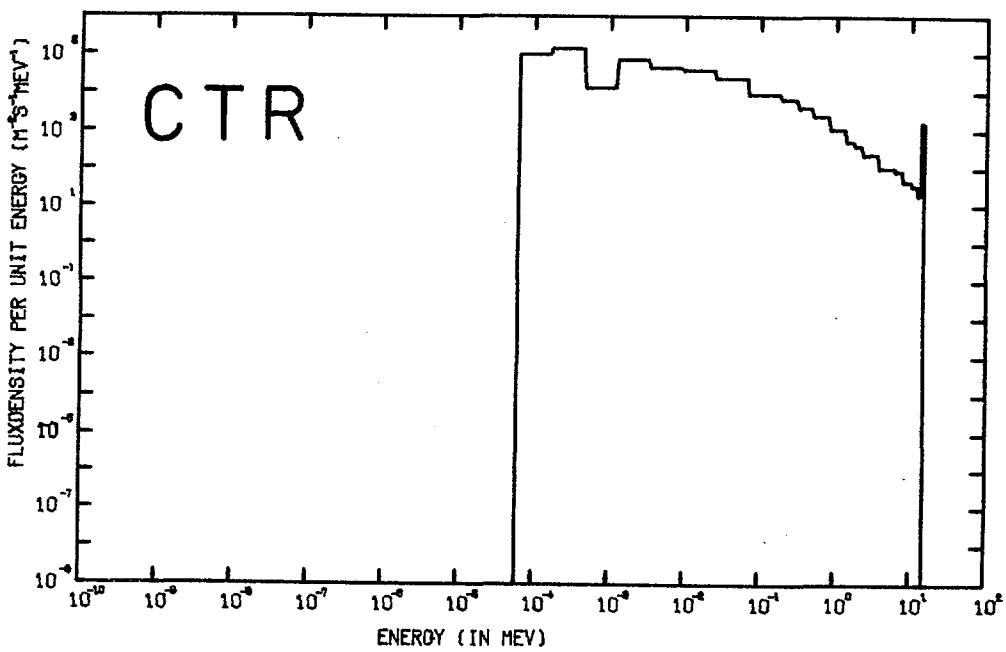
   The CTR TOKAMAK neutron spectrum is obtained from |Di79|.

   Both types of plots are included for illustration purposes only.

The reference flux density spectra are shown below.



HFR SPECTRUM.



CTR SPECTRUM (TOKAMAK) REF |DI79|

List of characteristics of the neutron spectra which are applied for the response functions are given in tables 8 and 9.

3. The plots are accompanied by energy ranges of response. A 90 per cent range means 5 per cent of the response below and 5 per cent above this range. A median is calculated, so that the responses below and above these ranges are equal.
   The CTR spectrum was obtained from |Di79|, the fission neutron spectra ^{252}Cf and ^{235}U are described by Grundl and Eisenhauer |Gr75|, |Gr77|, the CFRMF data come from Roger et al. |Ro78|, the ΣΣ data come from Fabry et al. |Fa75|, the MTR spectrum is a spectrum for an experiment position in the middle of the fuel region of the High Flux Reactor at Petten.

It is hoped that the next edition can refer to fission yield data of the ENDF/B-V file which in the near future will become available.

All people interested in reactor radiation measurements are invited to give their comments on the contents of this report.

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Scope of document

Neutron metrologists have interest in a few fission product nuclides characterized by a suitable half-life, a prominent gamma ray transition, and a reasonable fission product yield. Of course all these data should be rather accurate i.e. have inaccuracies which are well known and are utmost $2\frac{1}{2}$ percent.

The fission products in which there is a main interest are : ^{95}Zr, ^{97}Zr, ^{103}Ru, ^{131}I, ^{132}Te, ^{137}Cs and ^{140}Ba (see e.g. McElroy etal |Mc75|),

In addition, the stable nuclide ^{148}Nd is very often used as burn-up monitor.

The fissionable isotopes which are most important in neutron metrology are ^{235}U, ^{238}U, ^{239}Pu and ^{237}Np.

The scope of the document is mainly determined by the nuclides mentioned above.

Some definitions :

For the sake of clarity and convenience, the following list of definitions is presented (based on |ISO-72| and |De78|).

Fission products are the nuclides produced either by fission or by the subsequent radioactive disintegration of the nuclides thus formed.

The fission yield is the fraction of fissions leading to fission products of a given type.

The independent fission yield (also called the direct fission yield or the primary fission yield) is the fraction of fissions giving rise to a particular nuclide before any beta or gamma decay has occurred.

The secondary fission yield is the fraction of fissions giving rise to the formation of a particular nuclide by the beta decay of precursors.
The secondary fission yield of a fission product is therefore equal to the sum of the independent yields of all precursors.

The cumulative fission yield is the fraction of fissions which have resulted in the formation of a given nuclide either directly or indirectly up to a specified time. If no time is specified, the yield is considered to be the asymptotic value.
The cumulative fission yield of a nuclide is therefore equal to the sum of the independent fission yield and the secondary fission yield for this nuclide.

The chain fission yield (also called mass fission yield or isobaric fission yield) is the fraction of fissions giving rise to nuclides with a particular nucleon number (i.e. mass number).
The chain fission yield is therefore the sum of the independent fission yields of all isobars.

The chain fission yield is also equal to the cumulative fission yield of the last member of the decay chain, if all isobars produced show β^- decay.

Sources of fission yield data

As C. Lammer and M. Lammer |La78| indicated, the currently available large fission data files in general only discern between thermal and "fast" neutron fission yields.
These evaluated "fast" yields are often obtained from averaging over results from measurements performed in a variety of fast reactor spectra as well as different fission neutron spectra.
From the comparison reported by Lammer et al, in November 1976 and published in 1978 |La78| no evidence was found for an energy dependence of the yields mentioned above, within the energy range of fast reactor neutrons. This allows the combination of different yield data taken in fast reactor spectra to give evaluated "fast reactor yields".

At the second ASTM-Euratom Symposium, held at Palo Alto, October 3-7, 1977, Maeck and Lammer (see |Ma78|)reported on the second IAEA Advisory Group Meeting on Fission Product Nuclear Data, held at Petten,September 5-9, 1977.
At this Petten meeting the question of the dependence of fission yields on neutron energy was discussed in considerable detail Cuninghame concluded in his review paper |Cu78| that the energy effect was in most cases smaller than the available accuracies.
However the requirement for yields accurate to about 1.5% for use in burn-up and neutron metrology studies certainly requires that the significance of the yield-energy relationship be known.
The major problem now existing is not the relevance of this dependence but rather, how can this dependence be deduced from the existing data.
Maeck and Lammer state also that the change in many yields with neutron energy is small (<5%), and that a comparison of absolute literature yields, which often carry uncertainties of 2 to 5%, in general does not allow drawing conclusions about the energy dependence.
From their review paper we take also the following remarks on the present status.

The most stringent requirements for yield data were expressed by those users who performed burn-up and neutron metrology studies. They require an accuracy of ± 1.5% for the fission yields of those nuclides which are used to determine the number of fission.
The review paper on the status of fission yield data was prepared by J.G. Cuninghame from Harwell, U.K. (see |Cu78|).
It was basically confined to a comparison of the major fission yield compilations (primarily those of Crouch |Cr77|, and Meek and Rider |Me77|). In default of a better method, the "current status" of the data and their accuracies was given as the simple mean of the different recommended values and accuracies.
It was especially noted that the errors assigned by Crouch were in general much higher than those assigned by Rider.

Tables 10 and 11 list the percentage of uncertainties in the fission yields from |Cu78|.

At the second ASTM-Euratom Symposium at Palo Alto there was also an important paper on fission yield data, by Gilliam et al |Gi78|, resulting from efforts in the U.S.A. in the framework of the Inter-laboratory LMFBR Reaction Rate (ILRR) program.
Since these recent data seem to have good quality, and have not yet been included in previous compilations and evaluations, these ILRR values have been presented as starting values. However, values from the work of Crouch, Cuninghame, Meek and Rider are also present in this document.
Table 12 lists a data set for selected fission products with half-lives longer than one day as used at PTB (Physikalisch-Technische Bundesanstalt, Braunschweig).

^{232}Th (n,f)

Material constants

Relative atomic mass of element	: A_r(Th)	= 232.0381(1)	|Ho79|,
Mass density	: ρ	= 11.72 $Mg.m^{-3}$	|We79|
Melting point	: T	= 2023.15 K = 1750°C	
Number of atoms per unit mass	: N_m	= $2.595\times10^{24} kg^{-1}$	
Number of atoms per unit volume	: N_v	= $30.42\times10^{27} m^{-3}$	
Isotopic mole fraction	: x(^{232}Th)	= 100% |Ho79|	

Disintegration data

The decay scheme is too complex to be shown here.

^{232}Th half-life 14.05(6)x10^9a |Lo78|

Normally ^{232}Th is in equilibrium with many or all of its daughter products.

Reactions with thorium

^{232}Th(n,γ)^{233}Th : $T_{\frac{1}{2}}$ =22.2 min |Wa77| ; σ_0= 7.40(8)b = 740 fm^2
I = 85(3) b = 8500 fm^2 |Mu73|

^{232}Th(n,f) F.P. : σ_0= 0.039(4) mb=0.0039 fm^2 |Mu73|

Fission yields |Cu78|

fission product nuclide	chain fission yield for fast reactor spectrum
^{95}Zr	0.0564
^{97}Zr	0.0435
^{103}Ru	0.00161
^{131}I	0.0163
^{137}Cs	0.0593
^{140}Ba	0.0789
^{144}Ce	0.0770

For more information see table 1 in the appendix.

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data :

for a ^{235}U fission spectrum : $\langle\sigma\rangle_c$ = 70.26 mb = 7.026 fm^2 |Zij77|

$\langle\sigma\rangle_m$ = 81.0(54) mb = 8.10 fm^2 |Fa78|

Response data

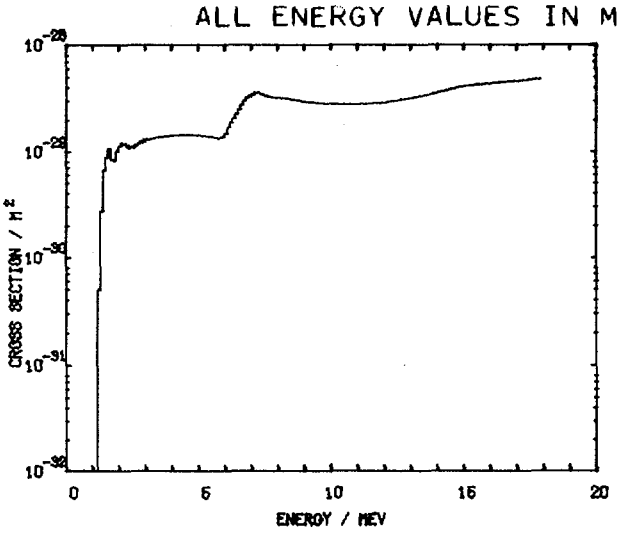
Effective threshold energy : E_T = 1.4 MeV |Fa78|

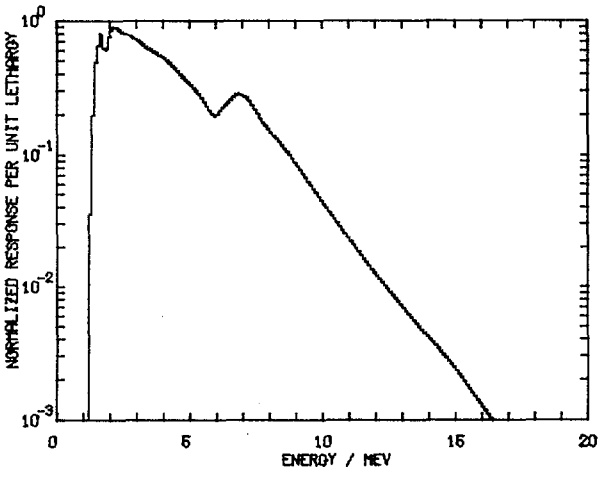
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: TH232(N,F)F P

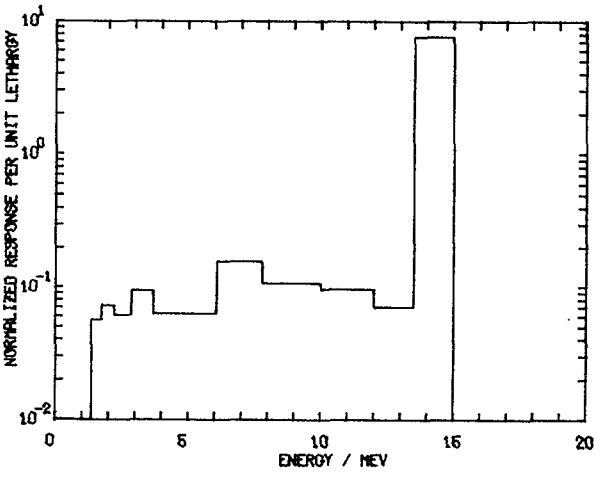
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	2.9E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.5E+00	7.6E+00	1.9E+00	4.9E+00	2.4E+00	3.7E+00	3.0E+00
235U	1.5E+00	7.2E+00	1.9E+00	4.6E+00	2.3E+00	3.5E+00	2.9E+00
CFRMF	1.4E+00	7.2E+00	1.7E+00	4.3E+00	2.1E+00	3.3E+00	2.6E+00
SIG.SIG.	1.4E+00	6.9E+00	1.7E+00	4.0E+00	2.1E+00	3.1E+00	2.5E+00
MTR	1.4E+00	7.1E+00	1.8E+00	4.3E+00	2.2E+00	3.3E+00	2.6E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

^{235}U (n,f)

Material constants

Relative atomic mass of element	$A_r(U)$	= 238.029(1)	|Ho79|
Mass density	ρ(silvery, cubic)	= 19.05(2) $Mg.m^{-3}$	|We79|
Melting point	T	= 1405.45K = 1132.3(8)°C	
Number of atoms per unit mass	N_m	= $2.530\times10^{24}kg^{-1}$	
Number of atoms per unit volume	N_v	= $48.20\times10^{27}m^{-3}$	
Isotopic mole fractions naturally occurring U	$x(^{234}U)$	= 0.005(1)%	|Ho79|
	$x(^{235}U)$	= 0.720(1)%	
	$x(^{238}U)$	=99.275(1)%	

Remark : The target material data are dependent on the enrichment Isotopic compositions may be given in terms of mole fraction (atom per cent), or in terms of mass fraction (mass per cent).

Disintegration data

The decay scheme is too complex to be shown here.

^{234}U $T_{\frac{1}{2}}$ = 2.446 (7) x 10^5 a ; |Va74|,|Lo78|

Main gamma transition

$E(\gamma)$ = 53.220(20) keV 0.118(19) |Ko77|

^{235}U $T_{\frac{1}{2}}$ = 7.038(7)$\times10^8$ a |Lo78|

Main gamma transitions

$E(\gamma)$=143.77 keV	(10.7(1) %)	
$E(\gamma)$=163.37 keV	(4.85(5)%)	
$E(\gamma)$=185.72 keV	(56.10(56) %)	
$E(\gamma)$=205.33 keV	(4.87(5) %)	

|Gu71|

^{238}U $T_{\frac{1}{2}}$ = 4.468(4) x 10^9 a |Lo78|

Normally the U isotopes are in equilibrium with many of their daughter products.

Reactions with uranium isotopes

$^{234}U(n,\gamma)^{235}U$: $T_{\frac{1}{2}}$ = 7.038(7)x10^8a |Lo78|;
σ_0 = 100.2(15)b = 10020 fm^2
I = 630(70) b = 63000 fm^2 } |Mu73|

^{234}U (n,f) F.P.: σ_0 < 0.65 b = < 65 fm^2 |Mu73|

$^{235}U(n,\gamma)^{236}U$: $T_{\frac{1}{2}}$ = 2.342(4)x10^7a |Lo78|;
σ_0 = 98.6(15) b = 9860 fm^2
I = 144(6) b = 14400 fm^2 } |Mu73|

$^{235}U(n,f)F.P.$: σ_0 = 576.9(34)b = 57690 fm^2 |Bi76|
I = 275(5) b = 27500 fm^2 |Mu73|

$^{236}U(n,\gamma)^{237}U$: $T_{\frac{1}{2}}$ = 6.75(1) d |Lo78|;
σ_0 = 5.2(3) b = 520 fm^2
I = 365(20) b = 36500 fm^2 } |Mu73|

$^{237}U(n,\gamma)^{238}U$: $T_{\frac{1}{2}}$ = 4.468(4)x10^9a |Lo78|;
σ_0 = 411(138) b = 41100 fm^2
I = 290 b = 29000 fm^2 } |Mu73|

^{237}U (n,f) F.P. : σ_0 < 0.35 b = < 35 fm^2 |Mu73|

$^{238}U(n,\gamma)^{239}U$: $T_{\frac{1}{2}}$ = 23.50(5) min |Lo78|;
σ_0 = 2.70(2) b = 270 fm^2
I = 275(5) b = 27500 fm^2 } |Mu73|

Fission yields

The following values have been obtained in the Interlaboratory LMFBR Reaction Rate (ILRR) program |Gi78|

fission product nuclide	cumulative fission yield for	
	thermal spectrum	fast reactor spectrum
^{95}Zr	0.0652 ± 2.6 %	0.0645 ± 2.2 %
^{97}Zr	0.0592 ± 4.1 %	0.0603 ± 2.4 %
^{103}Ru	0.0302 ± 2.6 %	0.0333 ± 2.3 %
^{131}I	0.0286 ± 4.6 %	0.0331 ± 4.3 %
^{132}Te	0.0421 ± 6.2 %	0.0483 ± 6.1 %
^{137}Cs	0.0612 ± 2.4 %	0.0626 ± 5.8 %
^{140}Ba	0.0622 ± 2.3 %	0.0610 ± 1.9 %
^{141}Ce	0.0572 ± 5.5 %	--
^{143}Ce	0.0536 ± 9.2 %	0.0517 ± 8.7 %
^{144}Ce	0.0572 ± 2.9 %	0.0583 ± 4.5 %

For more information on these values see table 2 in the appendix. For other evaluated data on fission yields see tables 3, 6 and 7 and reference |Cu78|.

Evaluated cross section data

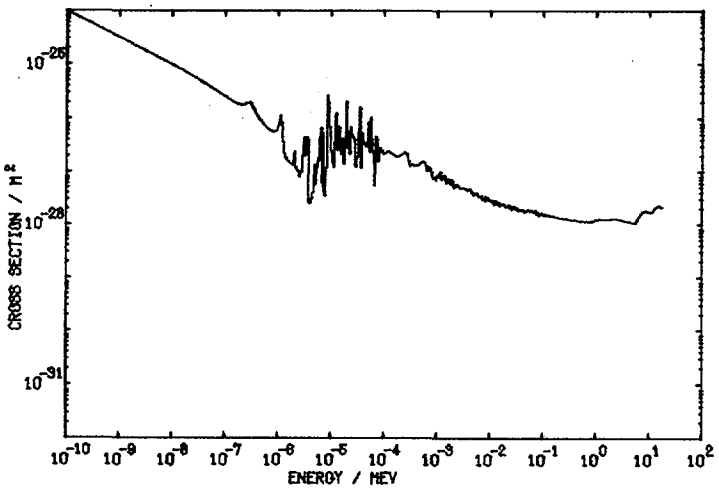
620 group data : |Ma75|, |Zij77|

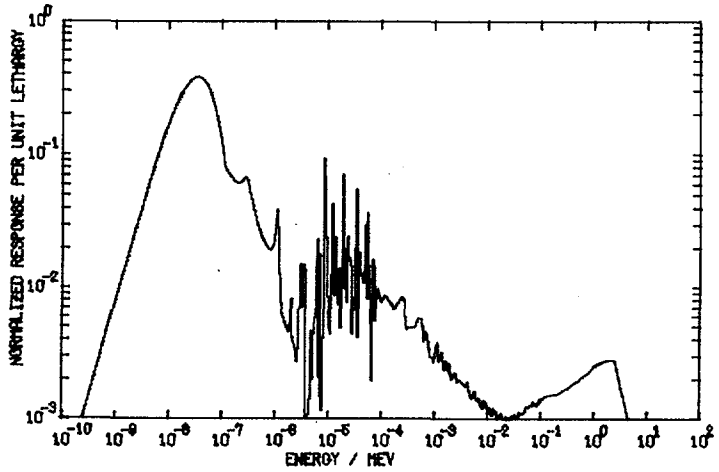
Integral data :	σ_0	= 576.9(34) b = 57690(340) fm^2	|Bi76|
	$g\sigma_0$	= 574.4 b = 57440 fm^2	|Zij77|
	I	= 270.2 b = 27020 fm^2	|Zij77|
	I	= 282.00 b = 28200 fm^2	|Ma75,2|
for a ^{235}U fission spectrum :	$\langle\sigma\rangle_m$	= 1203(30)mb = 120.3 fm^2	|Fa78|
	$\langle\sigma\rangle_c$	= 1241 mb = 124.1 fm^2	|Zij77|
	$\langle\sigma\rangle$	= 1243.2 mb = 124.32 fm^2	|Ma75,2|
for a ^{252}Cf fission spectrum:	$\langle\sigma\rangle_m$	= 1203(30) mb = 120.3 fm^2	|Fa78|

RESPONSE DATA FOR THE REACTION: U235(N,F)FP

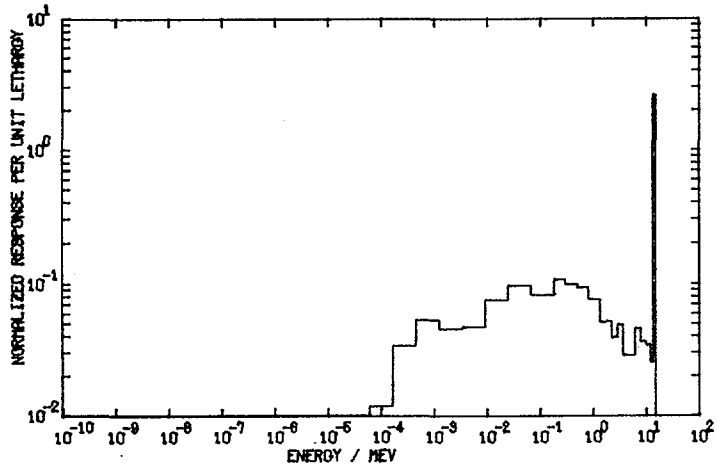
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	4.5E-04	1.4E+01	9.1E-03	1.4E+01	2.5E-02	1.7E+00	1.8E-01
252CF	2.2E-01	5.7E+00	6.9E-01	3.2E+00	1.1E+00	2.3E+00	1.6E+00
235U	1.9E-01	5.2E+00	6.3E-01	3.0E+00	1.0E+00	2.1E+00	1.5E+00
CFRMF	4.5E-04	2.5E+00	1.7E-02	8.0E-01	9.2E-02	4.0E-01	2.2E-01
SIG.SIG.	6.6E-04	2.6E+00	3.6E-02	9.2E-01	1.3E-01	4.8E-01	2.6E-01
MTR	4.8E-09	2.3E-05	1.4E-08	1.1E-07	2.3E-08	5.3E-08	3.4E-08

ALL ENERGY VALUES IN MEV.





MTR



CTR

^{238}U (n,f)

Material constants
Disintegration data
Reaction with U-isotopes
} See data for ^{235}U (n,f)

Fission yields

The following values have been obtained in the Interlaboratory LMFBR Reaction Rate (ILRR) program |Gi78|

Fission product nuclide	cumulative fission yield for a fast reactor spectrum	
^{95}Zr	0.0519	± 2.6 %
^{97}Zr	0.0568	± 3.0 %
^{103}Ru	0.0634	± 2.5 %
^{131}I	0.0326	± 4.3 %
^{137}Cs	0.0600	± 4.5 %
^{140}Ba	0.0600	± 2.2 %
^{143}Ce	0.0421	± 8.7 %
^{144}Ce	0.0495	± 4.3 %

For more information on these values see table 3 in the appendix. For other evaluated data on fission yields see tables 6 and 7 and reference |Cu78|.

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data : $g\sigma_0$ = 4.625 nb = 4625 am^2 |Zij77|
I = 2.58 mb = 0.258 fm^2

for a ^{235}U fission spectrum : $\langle\sigma\rangle_c$ = 301.6 mb = 30.16 fm^2 |Zij77|
$\langle\sigma\rangle_m$ = 305(10) mb = 30.5 fm^2 |Fa78|
$\langle\sigma\rangle$ = 295.4 mb = 29.54 fm^2 |Ma75,2|

for a ^{252}Cf fission spectrum: $\langle\sigma\rangle_m$ = 320(9) mb = 32 fm^2 |Fa78|

Remarks |AS78|

It is recommended to apply depleted uranium, i.e. uranium containing less than about 40 ppm ^{235}U.*
The uranium detector should be encapsulated in a suitable container to prevent loss of, and contamination of the surroundings by ^{238}U and its fission products.
The uranium detector should be surrounded with a thermal neutron absorbing material (e.q. a cadmium or boron cover) to minimize or to prevent thermal fission of trace quantities of ^{235}U in the ^{238}U target, or fission of ^{239}Pu produced by the reaction ^{238}U (n,γ) ^{239}U.

Response data

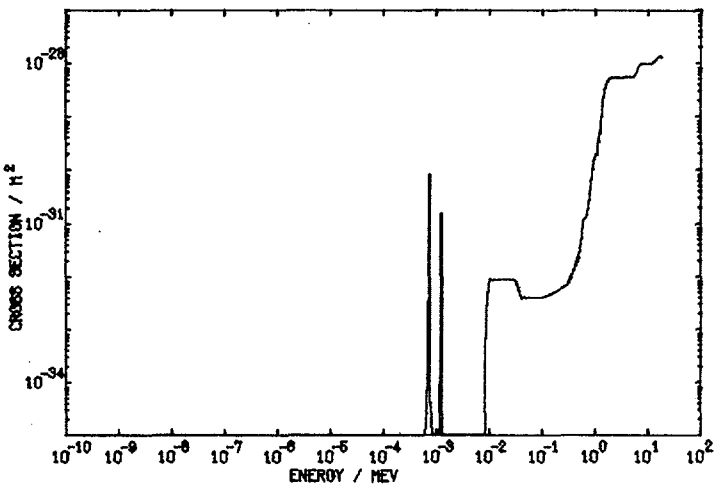
Effective treshold energy : E_T = 1.5 MeV.
For table and figures see next page.

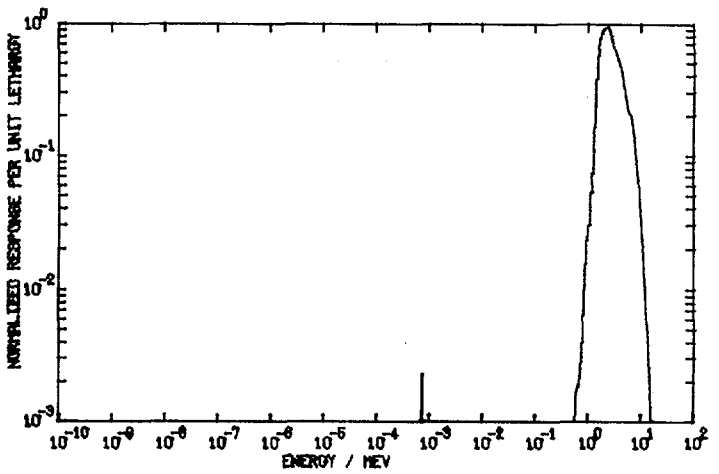
*or even less than 15 ppm ^{235}U (according to recent information supplied by H. Tourwé, Mol, Belgium).

RESPONSE DATA FOR THE REACTION: U238(N,F)FP

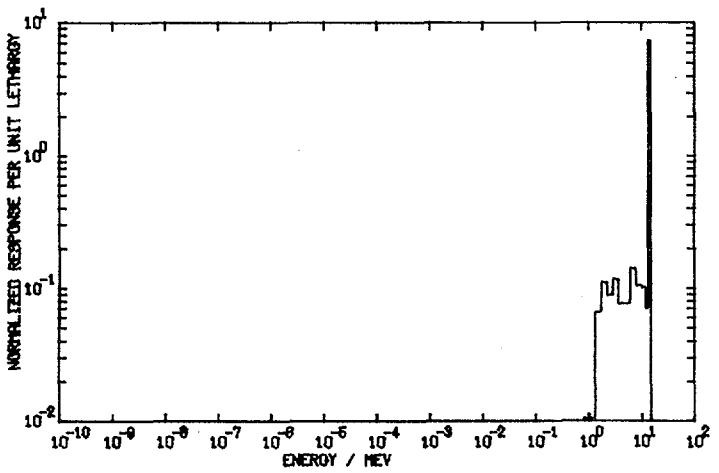
SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	2.2E+00	1.4E+01	7.8E+00	1.4E+01	1.4E+01	1.4E+01	1.4E+01
252CF	1.5E+00	7.2E+00	1.9E+00	4.5E+00	2.3E+00	3.5E+00	2.8E+00
235U	1.5E+00	6.7E+00	1.8E+00	4.2E+00	2.2E+00	3.3E+00	2.7E+00
CFRMF	1.4E+00	6.7E+00	1.7E+00	4.0E+00	2.1E+00	3.0E+00	2.5E+00
SIG.SIG.	1.4E+00	6.3E+00	1.7E+00	3.7E+00	2.0E+00	2.9E+00	2.4E+00
MTR	1.4E+00	6.5E+00	1.8E+00	4.0E+00	2.1E+00	3.0E+00	2.5E+00

ALL ENERGY VALUES IN MEV.





MTR



CTR

^{237}Np (n,f)

Material constants :

Relative atomic mass of element:	A_r(Np)	= 237.0482(1)	|Ho79|,
Mass density	: ρ	= 20.25 $Mg.m^{-3}$	|We79|
Melting point	: T	= 913.15 K = 640(1) ^oC	
Number of atoms per unit mass	: N_m	= $2.541\times10^{24} kg^{-1}$	
Number of atoms per unit volume:	N_v	= $51.45\times10^{27} m^{-3}$	

Disintegration data :

The decay scheme is too complex to be shown here.

^{237}Np : half-life = 2.14(1)x10^6 a |Lo78|

Normally ^{237}Np may be accompanied by some or all of its daughter products.

Reactions with ^{237}Np

^{237}Np (n,γ)^{238}Np : $T_{\frac{1}{2}}$ = 2.117(2) d |Lo78|; σ_o= 169(3)b=16900 fm^2 I = 660(50)b=66000 fm^2 |Mu73|

^{237}NP (n,f) F.P. : σ_o= 0.019(3)b=1.9 fm^2 |Mu73|

Fission yields

The following values have been obtained in the Interlaboratory LMFBR Reaction Rate (ILRR) program |Gi78|

fission product nuclide	cumulative fission yield for fast reactor spectrum	
^{95}Zr	0.0593	± 4.0 %
^{97}Zr	0.0683	± 3.8 %
^{103}Ru	0.0589	± 4.3 %
^{137}Cs	0.0650	± 5.2 %
^{140}Ba	0.0574	± 3.6 %

For more information on these values see table 4 in the appendix.
For other evaluated data on fission yields see table 7 and reference |Cu78|.

Evaluated cross section data

620 group data : |Ma75|, |Zij77|

Integral data :	σ_o = 0.019(3) b = 1.9 fm^2	|Mu73|
	$g\sigma_o$ = 16.1 mb = 161 fm^2	|Zij77|
	I = 1.214 b = 121.4 fm^2	|Zij77|
for a ^{235}U fission spectrum :	$\langle\sigma\rangle_m$= 1312(50) mb = 131.2 fm^2	|Fa78|
	$\langle\sigma\rangle_c$= 1337 mb = 133.7 fm^2	|Zij77|
	$\langle\sigma\rangle$ = 1322.8 mb = 132.28 fm^2	|Ma75,2|
for a ^{252}Cf fission spectrum:	$\langle\sigma\rangle_m$= 1332(37) mb = 133.2 fm^2	|Fa78|

Remarks |As78|

The neptunium detector should be encapsulated in a suitable container to prevent loss and contamination of the surroundings by the ^{237}Np and its fission products.
The neptunium detector should be surrounded with a thermal neutron absorbing material (e.q. a cadmium or boron cover) to minimize or prevent fission product formation from trace quantities of fissionable nuclides in the ^{237}Np target and from ^{238}Np and ^{238}Pu from (n,γ) reactions in the ^{237}Np material.

Response data

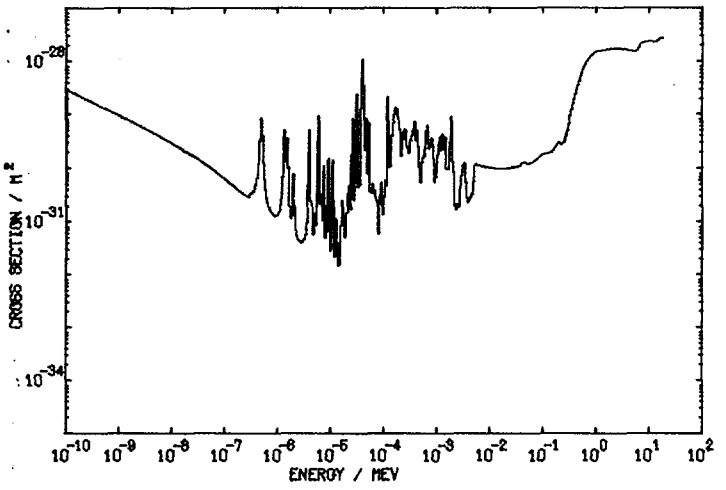
Effective treshold energy : E_T = 0.6 MeV.

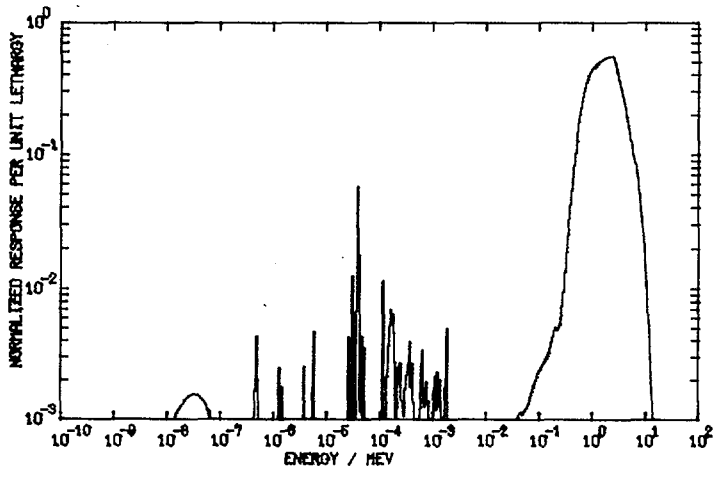
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: NP237(N,F)F P

SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	5.0E-01	1.4E+01	1.4E+00	1.4E+01	6.1E+00	1.4E+01	1.4E+01
252CF	6.9E-01	6.1E+00	1.1E+00	3.6E+00	1.5E+00	2.6E+00	2.0E+00
235U	6.6E-01	5.6E+00	1.1E+00	3.3E+00	1.5E+00	2.5E+00	1.9E+00
CFRMF	4.3E-01	4.5E+00	6.6E-01	2.4E+00	8.8E-01	1.6E+00	1.1E+00
SIG.SIG.	4.5E-01	4.2E+00	6.9E-01	2.3E+00	8.8E-01	1.6E+00	1.1E+00
MTR	5.0E-01	5.0E+00	8.8E-01	2.9E+00	1.2E+00	2.1E+00	1.6E+00

ALL ENERGY VALUES IN MEV.





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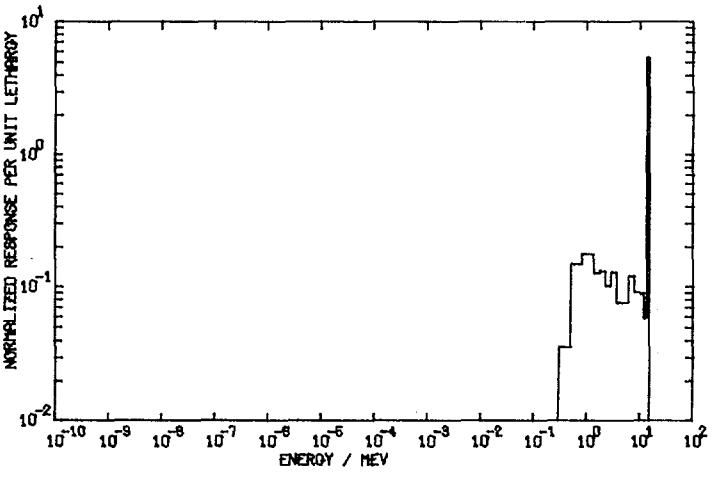


CTR

^{239}Pu (n,f)

Material constants

Relative atomic mass of element: $A_r(^{239}Pu) = 239.13$
Mass density : $\rho(\alpha$ modification$)=1984.Mg.m^{-3}$ |We79|
Melting point : $T = 914.15K = 641^oC$
Number of atoms per unit mass : $N_m = 2.519\times10^{24}kg^{-1}$
Number of atoms per unit volume: $N_v = 49.97\times10^{27}m^{-3}$

Disintegration data

The decay scheme is too complex to be shown here.
^{239}Pu half-life : $2.411(3)\times10^4$ a |Lo78|

Reactions with ^{239}Pu

^{239}Pu (n,γ)^{240}Pu : $T_{\frac{1}{2}} = 6.553(8)\times10^3$ a |Lo78|;
$\sigma_0 = 268.8(30)$ b $= 26880(300)$ fm^2
I $= 200(20)$ b $= 20000$ fm^2 |Mu73|

^{239}Pu (n,f) F.P. : $\sigma_0 = 742.8(44)$ b $= 74280(440)$ fm^2 |Bi76|
I $= 301(10)$ b $= 30100$ fm^2 |Mu73|

Fission yields

The following values have been obtained in the Interlaboratory LMFBR Reaction Rate program|Gi78|.

fission product nuclide	cumulative fission yield for thermal spectrum |Cu78|	cumulative fission yield for fast reactor spectrum |Gi78|
^{95}Zr	0.0499 ± 2.5 %	0.0480 ± 2.3 %
^{97}Zr	0.0555 ± 5.9 %	0.0544 ± 2.5 %
^{103}Ru	0.0638 ± 3.2 %	0.0708 ± 2.3 %
^{132}Te	0.0525 ± 3.7 %	0.0544 ± 6.1 %
^{137}Cs	0.0665 ± 1.7%%	0.0676 ± 2.6 %
^{140}Ba	0.0556 ± 3.5 %	0.0531 ± 2.0 %
^{143}Ce	0.0447 ± 3.8 %	0.0390 ± 8.7 %
^{144}Ce	0.0378 ± 3.8 %	0.0379 ± 5.5 %

For more information on these values see table 5 in the appendix.
For other evaluated data on fission yields see table 7 and reference |Cu78|.

Evaluated cross section data

620 group data : |Ma75| , |Zij77|

Integral data : σ_0 = 742.8(44) b = 74280(440) fm^2 |Bi76|

$g\sigma_0$ = 785.3 b = 78530 fm^2 |Zij77|

I = 291.9 b = 29190 fm^2 |Zij77|

I = 303.90 b = 30390 fm^2 |Ma75,2|

for a ^{235}U fission spectrum : $\langle\sigma\rangle_m$ =1811(60) mb=181.1 fm^2 |Fa78|

$\langle\sigma\rangle_c$ =1786 mb =178.6 fm^2 |Zij77|

$\langle\sigma\rangle$ =1782.4 mb =178.24fm^2 |Ma75,2|

for a ^{252}Cf fission spectrum: $\langle\sigma\rangle_m$ =1804(45) mb=180.4 fm^2 |Fa78|

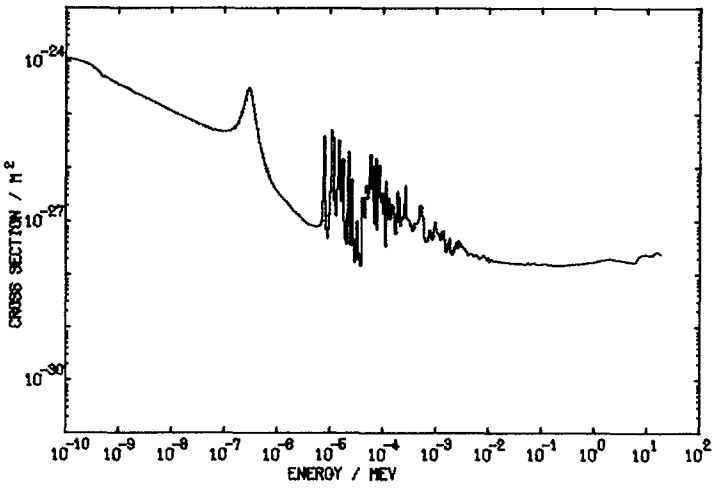
Response data

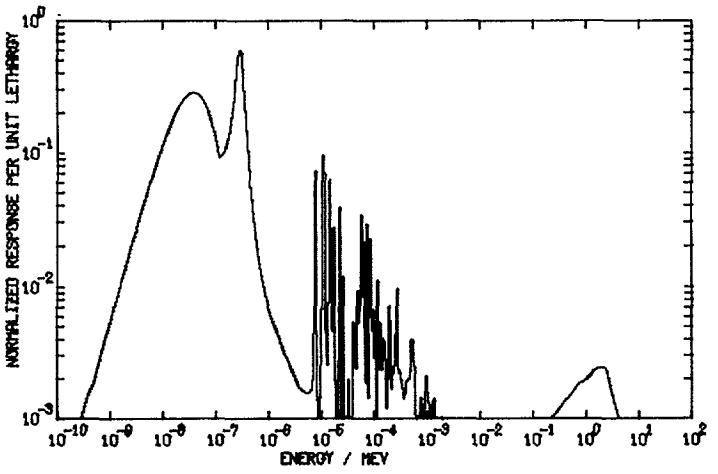
For table and figures see next page.

RESPONSE DATA FOR THE REACTION: PU239(N,F)FP

SPECTRUM	ENERGY RANGE OF RESPONSE						
	90 PER CENT		60 PER CENT		30 PER CENT		
	E LOWER	E UPPER	E LOWER	E UPPER	E LOWER	E UPPER	E MEDIAN
CTR	4.5E-04	1.4E+01	2.5E-02	1.4E+01	1.8E-01	3.7E+00	5.0E-01
252CF	2.8E-01	5.7E+00	7.6E-01	3.3E+00	1.2E+00	2.3E+00	1.7E+00
235U	2.6E-01	5.2E+00	7.2E-01	3.0E+00	1.1E+00	2.2E+00	1.6E+00
CFRMF	5.5E-04	2.9E+00	6.0E-02	1.0E+00	1.8E-01	5.8E-01	3.4E-01
SIG.SIG.	9.2E-04	2.9E+00	8.0E-02	1.1E+00	2.1E-01	6.6E-01	4.0E-01
MTR	6.3E-09	7.2E-06	1.9E-08	2.8E-07	3.4E-08	1.7E-07	6.0E-08

ALL ENERGY VALUES IN MEV.





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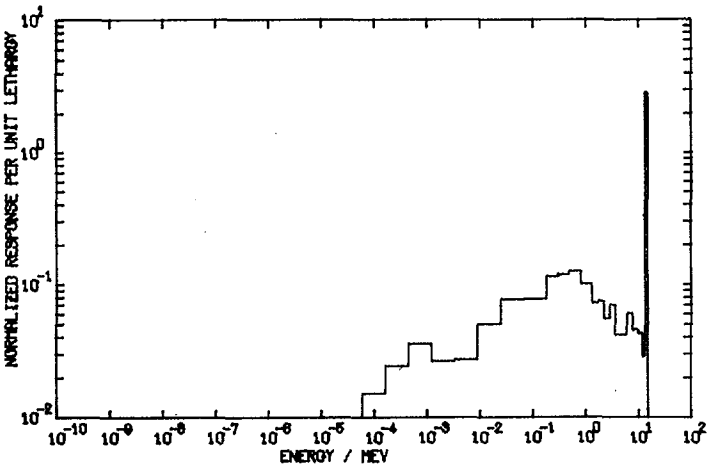
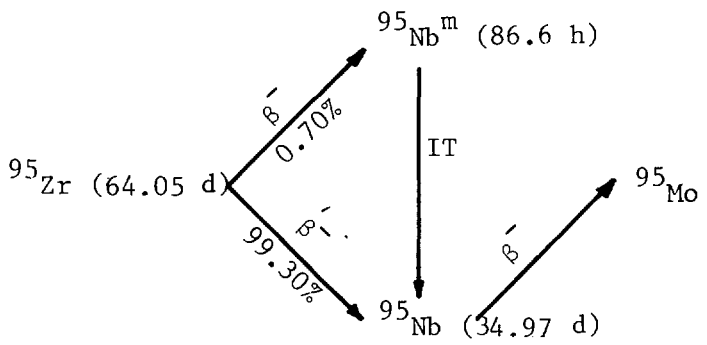


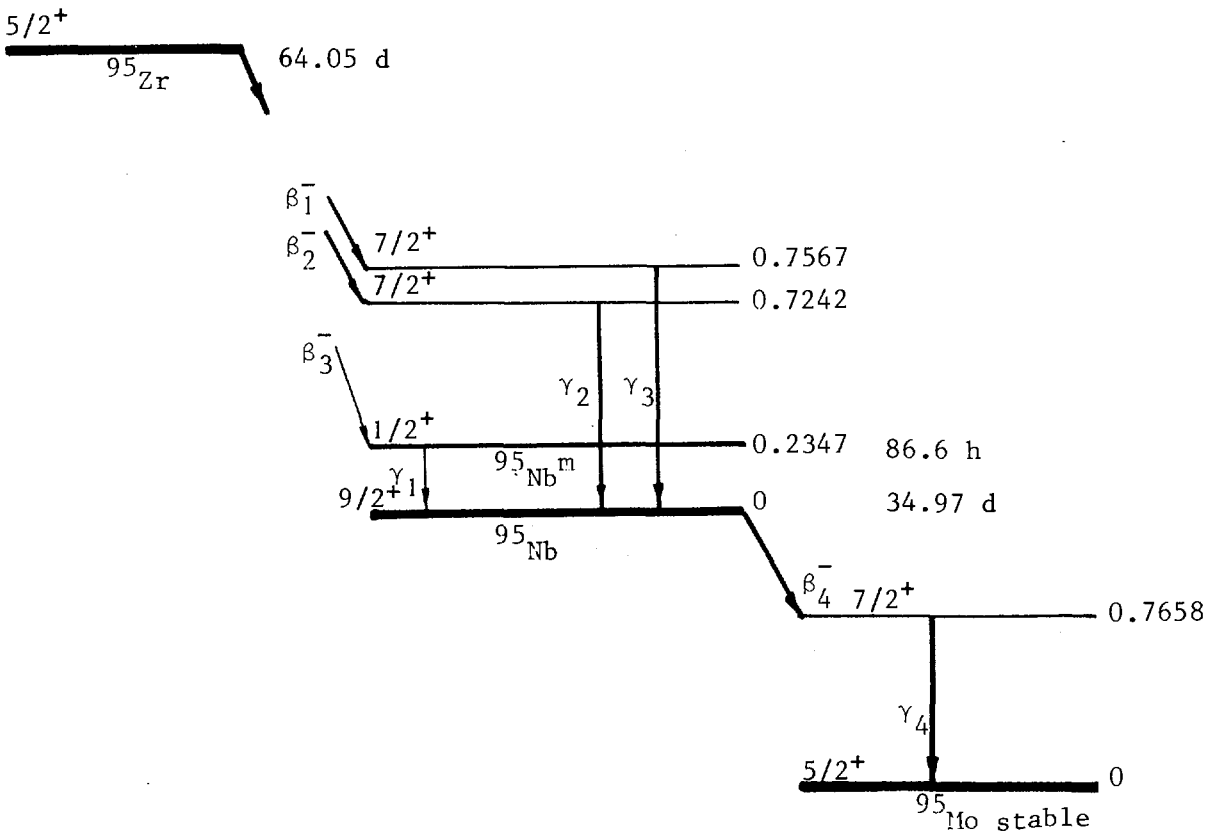
CTR

^{95}Zr - ^{95}Nb

Diagram of radioactive decay chain



Disintegration scheme



Disintegration data |MED78|

^{95}Zr $T_{\frac{1}{2}}$ = 64.05 (6) d |Ha76|

λ = 1.2525×10^{-7} s^{-1}

$E(\beta_1^-)$ max 365 (4) keV

av 108.8 (13) keV 55.0 (3) %

$E(\beta_2^-)$ max 398 (4) keV

av 120.0 (13) keV 44.6 (6) %

$E(\beta_3^-)$ max 887 (4) keV

av 326.9 (15) keV 0.70(6) %

$E(\gamma_2)$ 724.23 (4) keV 44.5 (6) %

$E(\gamma_3)$ 756.74 (4) keV 55.0 (3) %

feeding to $^{95}Nb^m$: 0.70(6)%; feeding to ^{95}Nb: 99.30(6)%.

$^{95}Nb^m$ $T_{\frac{1}{2}}$ = 86.6 (8) h

λ = 2.2233×10^{-6} s^{-1}

$E(\gamma_1)$ 234.70(14) kev 26.1 (6) % *

^{95}Nb $T_{\frac{1}{2}}$ = 34.97 d |Ha76|

λ = 2.2941×10^{-7} s^{-1}

$E(\beta_4^-)$ max 159.7 (5) keV

av 43.33(15) keV 100 %

$E(\gamma_4)$ 765.83 (4) keV 100 % **

* The equilibrium mixture $^{95}Zr + {}^{95}Nb^m$ has for this transition a gamma-ray emission probability of $\frac{0.007\times64.05\times24}{64.05\times24 - 86.6} \times 26.1 = 0.00742\times26.1 =$ 0.19(2)%.

Another evaluated value for the gamma-ray emission probability of the 234.70 keV transition of $^{95}Nb^m$ is 25.6(5)% |Le78,2|.

However, with respect to the decay of the equilibrium mixture of $^{95}Zr + {}^{95}Nb^m$ one has for this transition a gamma-ray emission probability of 0.29(5)% |Le78,2|.

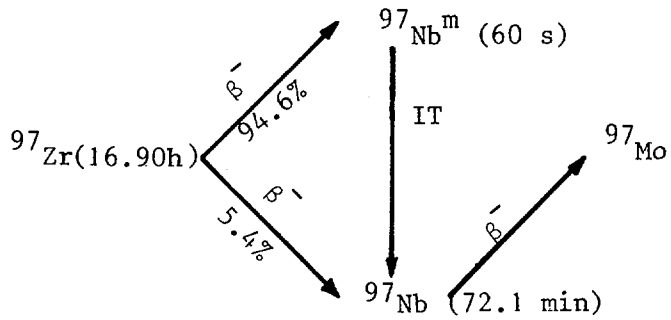
The feeding to $^{95}Nb^m$ was here 1.07(10)%.

The half-lives: $T_{\frac{1}{2}}$ ^{95}Zr = 63.98(6) d
$T_{\frac{1}{2}}$ $^{95}Nb^m$ = 3.61(12)d } |Le78,2|

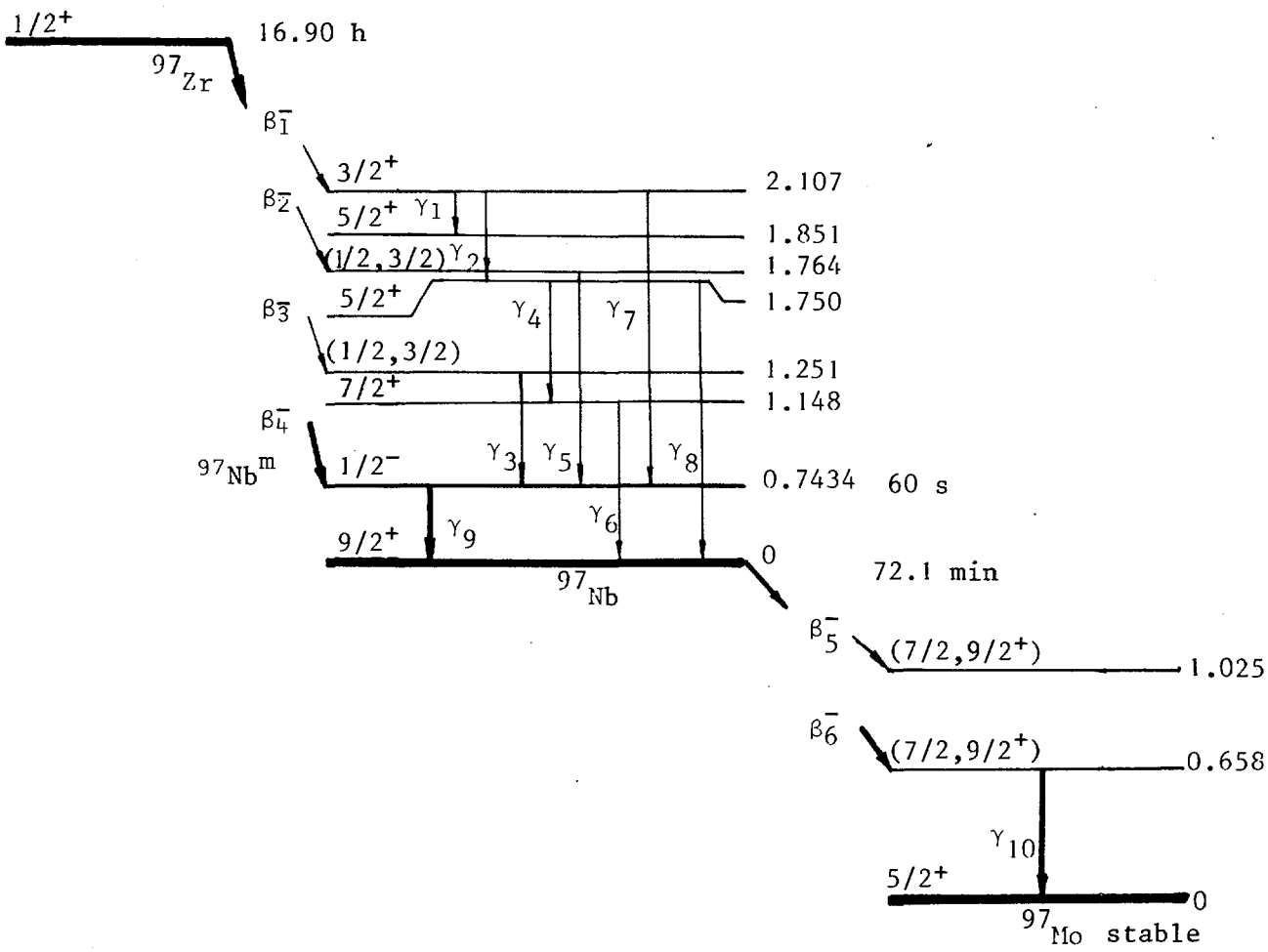
**If ^{95}Nb is in radioactive equilibrium with ^{95}Zr, the gamma ray emission probability per decay of ^{95}Zr is 220.3%. Under usual measuring conditions this equilibrium is not reached.

^{97}Zr - ^{97}Nb

Diagram of radioactive decay chain



Disintegration scheme |NDS73|, |Kr78|



Disintegration data |MED78|

^{97}Zr $T_{\frac{1}{2}}$ = 16.90 (5) h

λ = $1.1393\times10^{-5}s^{-1}$

$E(\beta_1^-)$	max	559 (16)	keV	
	av	178 (6)	keV	5.5 (3) %
$E(\beta_2^-)$	max	901 (16)	keV	
	av	312 (6)	keV	2.10 (20) %
$E(\beta_3^-)$	max	1414 (16)	keV	
	av	532 (7)	keV	4.1 (5) %
$E(\beta_4^-)$	max	1922 (16)	keV	
	av	760 (8)	keV	86.0 (7) %
$E(\gamma_1)$		254.15(20)	keV	1.25 (14) %
$E(\gamma_2)$		355.39(10)	keV	2.27 (24) %
$E(\gamma_3)$		507.63(10)	keV	5.1 (6) %
$E(\gamma_4)$		602.41(20)	keV	1.39 (14) %
$E(\gamma_5)$		1021.3 (3)	keV	1.34 (14) %
$E(\gamma_6)$		1147.95(10)	keV	2.6 (3) %
$E(\gamma_7)$		1362.66(10)	keV	1.34 (14) %
$E(\gamma_8)$		1750.46(10)	keV	1.34 (14) %

feeding to $^{97}Nb^m$: 94.6(9)%; feeding to ^{97}Nb: 5.4(9)%.

$^{97}Nb^m$ $T_{\frac{1}{2}}$ = 60 (1) s

λ = $1.1552\times10^{-2}s^{-1}$

$E(\gamma_9)$	743.36(10)	keV	97.95 (6) %

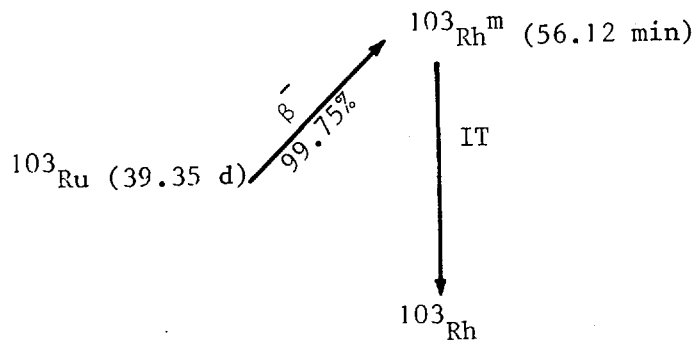
^{97}Nb $T_{\frac{1}{2}}$ = 72.1 (7) min

λ = $1.6023\times10^{-4}s^{-1}$

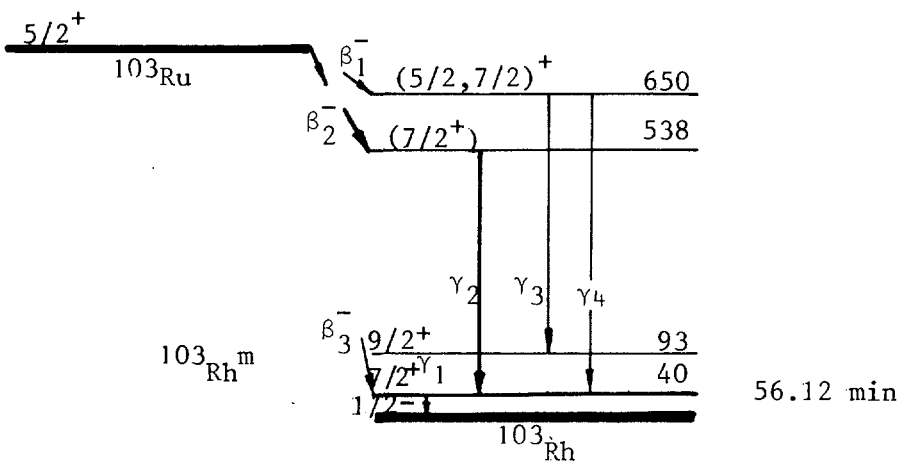
$E(\beta_5^-)$	max	910 (16)	keV	
	av	315 (6)	keV	1.10 (10) %
$E(\beta_6^-)$	max	1276 (16)	keV	
	av	470 (7)	keV	98.30(10) %
$E(\gamma_{10})$		657.92(10)	keV	98.34(11) %

^{103}Ru - ^{103}Rh

Diagram of radioactive decay chain



Disintegration scheme



Disintegration data |MED78|

^{103}Ru $T_{\frac{1}{2}}$ = 39.276(9) d |De79|

λ = $2.0426\times10^{-7}\,s^{-1}$

$E(\beta_1^-)$	max	112	(4)	keV		
	av	29.5	(10)	keV	6.5(1)%	
$E(\beta_2^-)$	max	225	(4)	keV		
	av	62.8	(11)	keV	91.4(8)%	
$E(\beta_3^-)$	max	722	(4)	keV		
	av	238.7	(14)	keV	2 (1)%	

|MED78| |PTB79|

	$E(\gamma_2)$	497.080(10) keV	|MED78|	90.9(7) %	|De79|
	$E(\gamma_3)$	557.040(20) keV		0.841(12)%	
	$E(\gamma_4)$	610.330(10) keV		5.65(7) %	

$^{103}Rh^m$ feeding to $^{103}Rh^m$: 99.75(1)%.

$T_{\frac{1}{2}}$ = 56.12 (1) min

λ = $2.0585 \times 10^{-4} s^{-1}$

$E(\gamma_1)$	39.8	keV	0.07	%
Auger-L	2.39	keV	76.6(15)	%
Ce-K-1	16.530(7)	keV	9.5(3)	%
Auger-K	17	keV	1.8(3)	%
Ce-L-1	36.338(7)	keV	71.290(10)	%
Ce-M-1	39.123(7)	keV	14.4(4)	%
Ce-NOP-1	39.669(7)	keV	4.70(20)	%
x-ray L	2.7	keV	4.0(13)	%
x-ray $K_{\alpha 2}$	20.07370(20)	keV	2.19(12)	%*
x-ray $K_{\alpha 1}$	20.21610(20)	keV	4.17(21)	%*
x-ray $K\beta$	22.7	keV	1.30(7)	%*

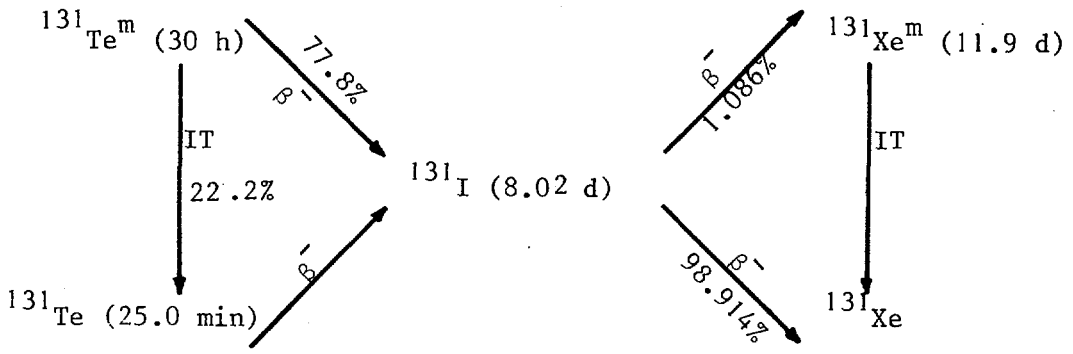
\|MED78\|

* ΣPKx = 7.66%.

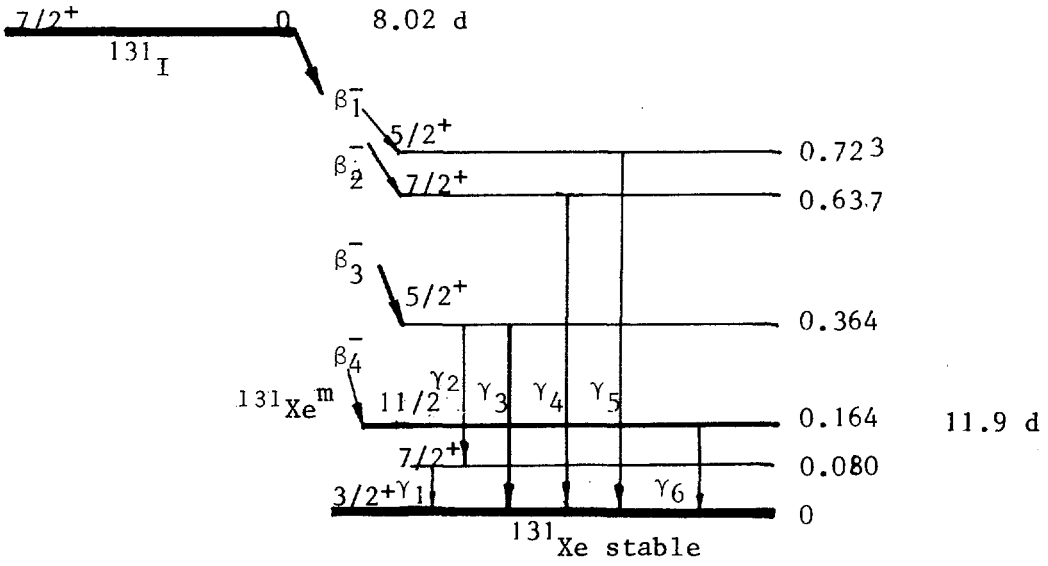
ΣPKx measurements at CBNM, Geel, result in a higher value: 8.4(5)%.

^{131}I

Diagram of radioactive decay chain



Disintegration scheme



Disintegration data |MED78|

^{131}I $T_{\frac{1}{2}}$ = 8.02 (1) d |De79|

λ = 1.0003x10^{-6}s^{-1}

$E(\beta_1^-)$	max	247.9 (6) keV	
	av	69.40(20) keV	2.13 (3) %
$E(\beta_2^-)$	max	333.8 (6) keV	
	av	96.60(20) keV	7.36(10) %
$E(\beta_3^-)$	max	606.3 (6) keV	
	av	191.60(30) keV	89.4 (10) %

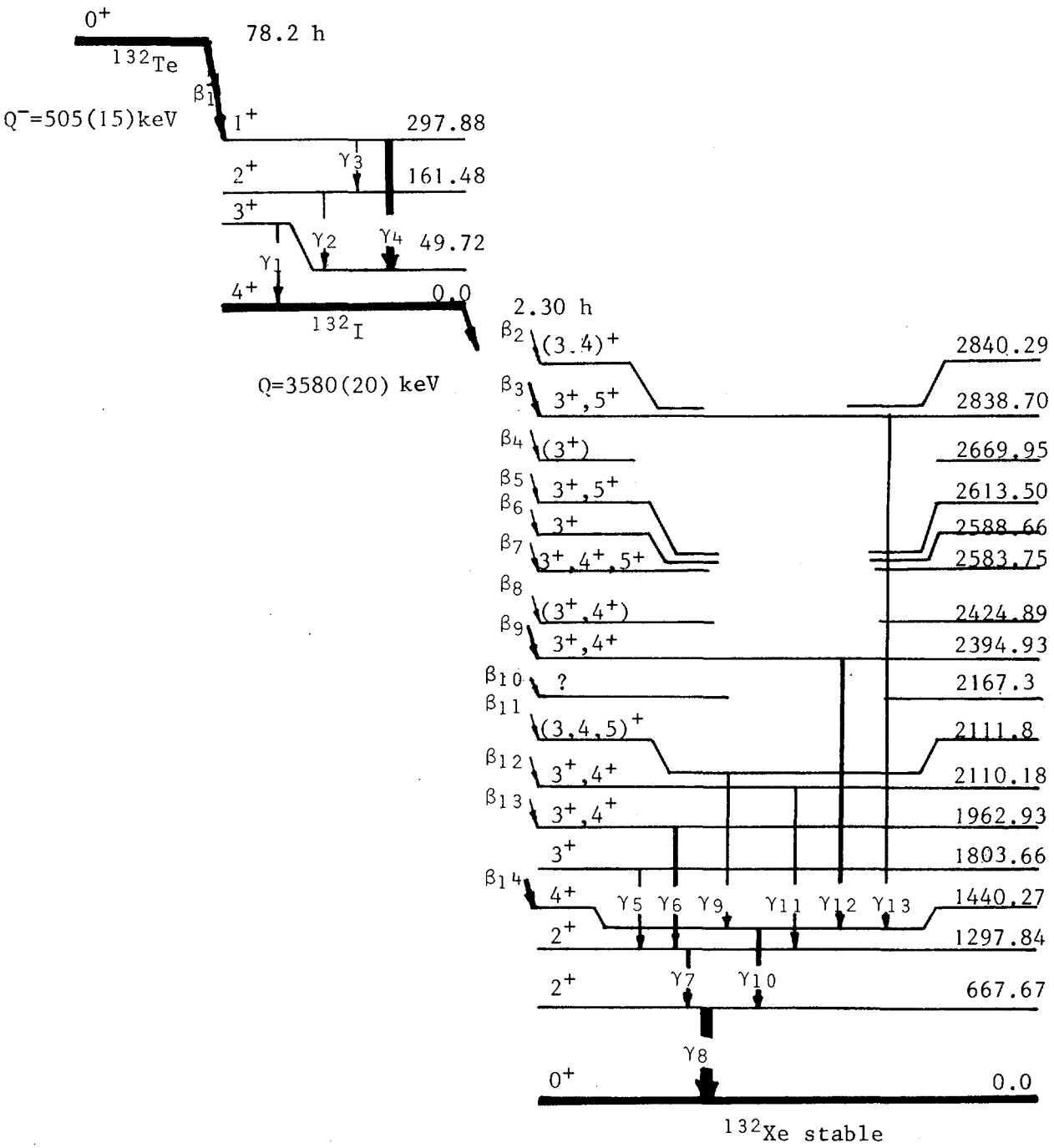
	$E(\beta_4^-)$ max	806.9 (6) keV		
	av	283.20 (30) keV	0.420(20) %	
	$E(\gamma_1)$	80.183(10) keV	2.62 (5) %	
	$E(\gamma_2)$	284.298(11) keV	6.06 (9) %	
	$E(\gamma_3)$	364.480(11) keV	81.2 (12) %	
	$E(\gamma_4)$	636.973(10) keV	7.27 (11) %	
	$E(\gamma_5)$	722.893(10) keV	1.801(3) %	
$^{131}Xe^m$	feeding to ^{131}Xe: 1.086(13)%.			
	$T_{\frac{1}{2}}$ = 11.9 (1) d			
	$\lambda = 6.7416\times10^{-7}s^{-1}$			
	$E(\gamma_6)$	163.930(8) keV	1.96 (6) %	

$^{132}Te-^{132}I$

Diagram of radioactive decay chain

^{132}Te (78.2 h) $\xrightarrow{\beta}$ ^{132}I (2.30 h) $\xrightarrow{\beta}$ ^{132}Xe.

Disintegration scheme |Hi76|



Disintegration data |MED78|

^{132}Te : half-life : $T_{\frac{1}{2}}$ = 76.9 (3) h |De79|

decay constant : λ = $2.5038 \times 10^{-6} s^{-1}$

$E(\beta_1^-)$ max 215(4) keV

av 59.4 (12) keV 100%

γ number	$E(\gamma)$(in keV)	P_γ (in %)
1	49.720(10)	14.4 (10)
2	111.76 (8)	1.85(18)
3	116.30 (8)	1.94(18)
4	228.16 (6)	88.2 (4)*

feeding ^{132}I: 100%.

^{132}I : half-life : $T_{\frac{1}{2}}$ = 2.30(3) h

decay constant : λ = $8.3713 \times 10^{-5} s^{-1}$

main β's

β^-number	$E(\beta^-)$max(in keV)	$E(\beta^-)$av (in keV)	P_{β^-} (in %)
2	740(20)	242 (8)	1.81(10)
3	741(20)	242 (8)	12.8 (8)
4	910(20)	309 (8)	3.60(20)
5	967(20)	331 (9)	8.1 (4)
6**	991(20)	342 (9)	2.53(15)
7	996(20)	344 (9)	3.79(16)
8	1155(20)	409 (9)	2.11 (7)
9	1185(20)	422 (9)	19.0 (7)
10	1413(20)	519 (9)	1.7 (6)
11	1468(20)	543 (9)	1.9 (8)
12	1470(20)	543 (9)	10.2 (10)
13	1617(20)	608 (9)	12.7 (7)
14	2140(20)	841 (9)	17.6 (22)
total β^-		490(11)	100 (3)

22 weak β's omitted ΣP_β = 2.29%.

* The quoted uncertainty is probably underestimated; 88.2(10) would be more realistic.

**The beta transition number 6 has been reported by |Hi76| but not by |MED78|.

main γ's

γ number	E(γ) (in keV)	P_γ (in %)
5	505.90)15)	5.03(20)
6	522.65 (9)	16.1 (6)
7	630.22 (9)	13.7 (6)
8	667.69 (8)	98.70(0)
9	671.6 (3)	5.2 (4)
10	772.60 (8)	76.2 (18)
11	812.20(20)	5.6 (5)
12	954.55 (9)	18.1 (6)
13	1398.57(10)	7.1 (3)

110 weak γ's omitted.

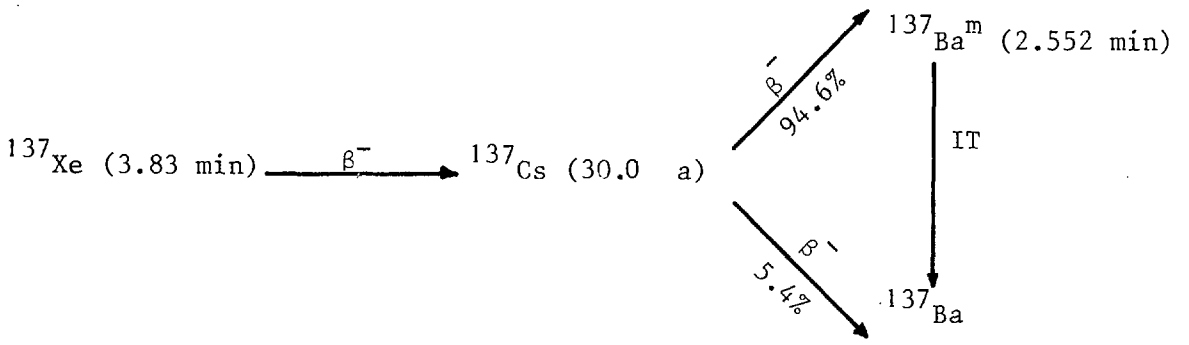
Remark:

Generally ^{132}I is measured in radioactive equilibrium with ^{132}Te. P_γ for ^{132}I γ-rays has to be multiplied by 1.031(5)* in order to get the number of ^{132}I γ-rays per decay of ^{132}Te.

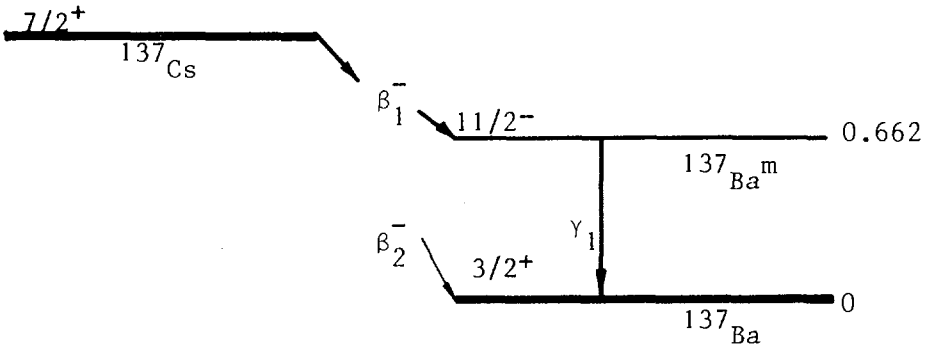
$$* \quad \frac{f_{\bullet} T_{\frac{1}{2}}(p)}{T_{\frac{1}{2}}(p) - T_{\frac{1}{2}}(d)} = \frac{1.00\ 76.9}{76.9-2.30} = 1.031.$$

^{137}Cs

Diagram of radioactive decay chain



Disintegration scheme



Disintegration data |MED78|

^{137}Cs $T_{\frac{1}{2}}$ = 30.0 (2) a *

λ = $7.3217\times10^{-10}s^{-1}$

$E(\beta_1^-)$ max 511.553(9) keV

av 173.5 (3) keV 94.6 (3) %

$E(\beta_2^-)$ max 1173.2 keV

av 415.4 (3) keV 5.4 (3) %

feeding $^{137}Ba^m$: 94.6(3)%.

$^{137}Ba^m$ $T_{\frac{1}{2}}$ = 2.552 (2) min

λ = $4.5268\times10^{-3}s^{-1}$

$E(\gamma_1)$ 661.645(9) keV 89.9 (4) %

The equilibrium mixture $^{137}Cs + ^{137}Ba^m$ has the main gamma-ray transition Eγ 661.645(9) keV with a probability of 94.6x0.899=85.0(5)%. per disintegration of ^{137}Cs.

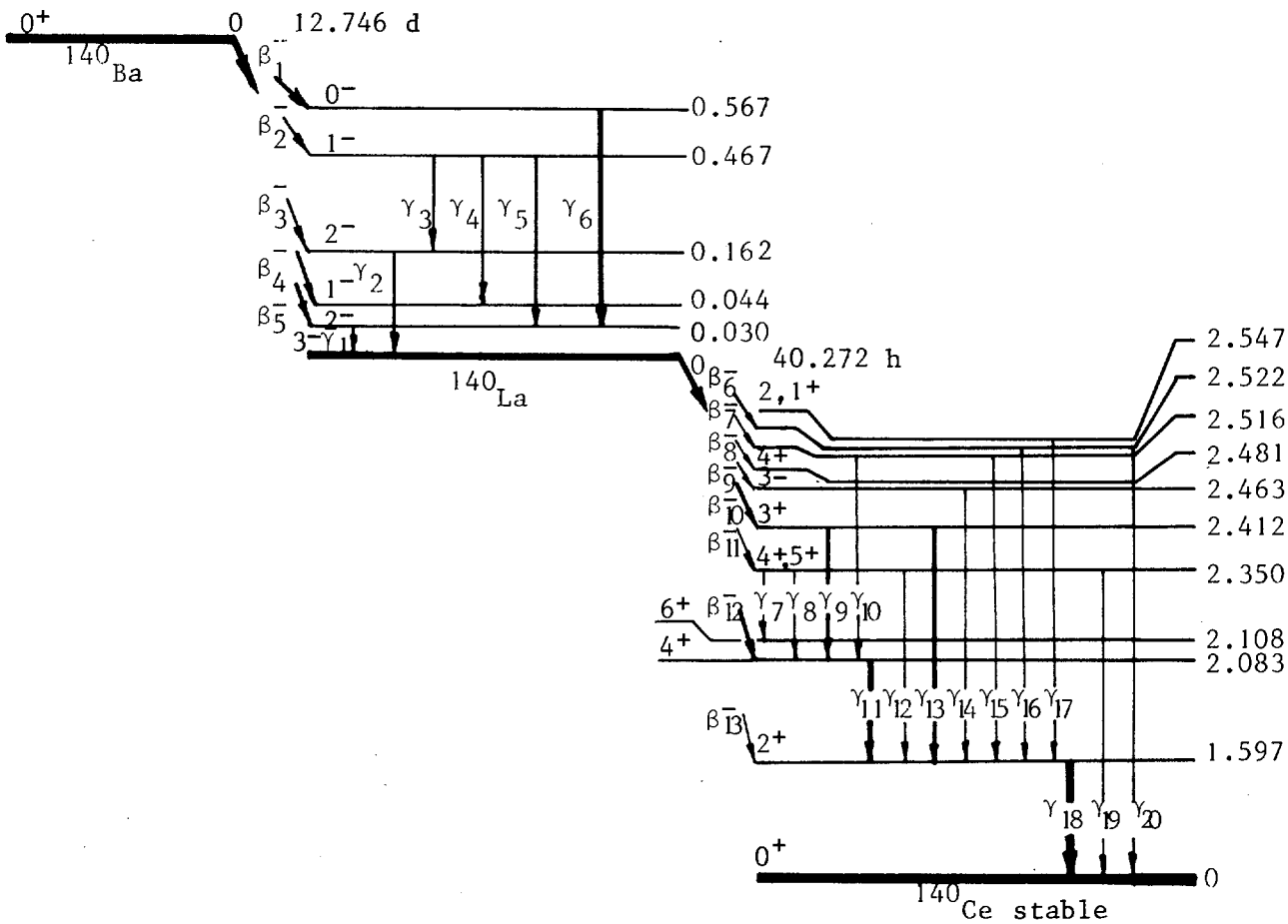
* 1a = 365.24220 d = 315569256 s |ISO75|

^{140}Ba - ^{140}La

Diagram of radioactive decay chain

$$^{140}Ba\ (12.746\ d) \xrightarrow{\beta^-} {}^{140}La\ (40.272h) \xrightarrow{\beta^-} {}^{140}Ce$$

Disintegration scheme



Disintegration data |MED78|

^{140}Ba : half-life : $T_{\frac{1}{2}}$ = 12.746(10) |De79|

decay constant : $\lambda = 6.2942 \times 10^{-7} s^{-1}$

β^- number	$E(\beta^-)$max(in keV)	$E(\beta^-)$av(in keV)	P_β (in %)
1	454 (10)	136 (4)	24.69 (22)
2	567 (10)	177 (4)	9.86 (8)
3	872 (10)	292 (4)	3.81 (12)
4	991 (10)	340 (4)	39 (4)
5	1005 (10)	357 (4)	23 (4)
total β^-		276 (5)	100 (6)

γ number	$E(\gamma)$(in keV)	P_γ (in %)
1	29.97 (5)	13.7 (4)
2	162.609(20)	6.21 (8)
3	304.850(10)	4.30 (5)
4	423.722(12)	3.15 (4)
5	437.575(20)	1.93 (4)
6	537.274(20)	24.39(21)

feeding ^{140}La: 100%.

^{140}La : half-life : $T_{\frac{1}{2}}$ = 40.272 (7) h

decay constant : $\lambda = 4.7810 \times 10^{-6} s^{-1}$

β^-number	$E(\beta^-)$ max(in keV)	$E(\beta^-)$av(in keV)	P_β (in %)
6	1238.8(20)	441.1(9)	11.09(13)
7	1244.4(20)	443.5(9)	5.74 (5)
8	1279.3(20)	458.2(9)	1.11 (7)
9	1296.2(20)	465.3(9)	5.61 (5)
10	1348.2(20)	487.4(9)	43.7 (3)
11	1412.3(20)	514.7(9)	5.11 (5)
12	1677.0(20)	629.5(9)	21.6 (5)
13	2164.0(20)	846.2(9)	5.0 (5)

γ number	E(γ)(in keV)	P_γ (in %)
7	241.966(12)	0.47 (3)
8	266.551(14)	0.452(25)
9	328.768(12)	20.74 (18)
10	432.520(20)	2.99 (4)
11	487.029(19)	45.9 (4)
12	751.83 (8)	4.41 (4)
13	815.78 (3)	23.64 (17)
14	867.84 (4)	5.59 (5)
15	919.54 (4)	2.68 (3)
16	925.19 (4)	7.05 (8)
17	951.00 (6)	0.539(19)
18	1596.17 (6)	95.40 (8)
19	2347.80 (6)	0.846(17)
20	2521.32 (6)	3.43 (8)

Remark : The 815.84 keV line of ^{140}La can be disturbed by the 812.20 keV line of the radionuclide ^{132}I, which is obtained from the fission product ^{132}Te.

When the radioactive equilibrium has been reached, the gamma-ray emission probabilities of ^{140}La have to be multiplied by

$$\frac{1.00\times12.746\times24}{12.746\times24-40.272} = 1.1516$$

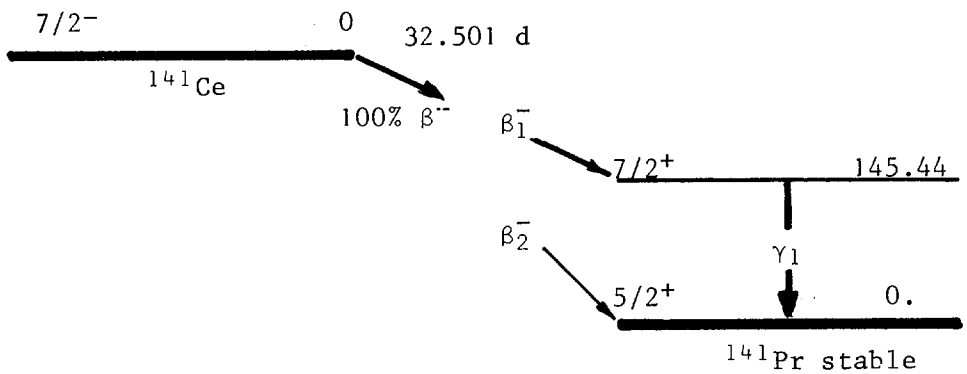
in order to get the number of ^{140}La gamma-rays per decay of ^{140}Ba.

^{141}Ce

Diagram of radioactive decay chain

$^{141}Ba(18.27\ min) \xrightarrow{\beta^-} {}^{141}La(3.93\ h) \xrightarrow{\beta^-} {}^{141}Ce(32.50\ d) \xrightarrow{\beta^-} {}^{141}Pr$

Disintegration scheme



Disintegration data |MED78|

^{141}Ce : half-life : $T_{\frac{1}{2}} = 32.501(5)$ d

decay constant : $\lambda = 2.4684 \times 10^{-7} s^{-1}$

β^-number	$E(\beta^-)$max.(in keV)	$E(\beta^-)$av.(in keV)	$P\beta^-$(in %)
1	434.6(15)	129.6(6)	70.5(7)
2	580.0(15)	180.7(6)	29.5(7)
$E\gamma_1$	145.440(10)		48.4(4)%

Remark: The ^{141}Ce can be formed with the reaction :

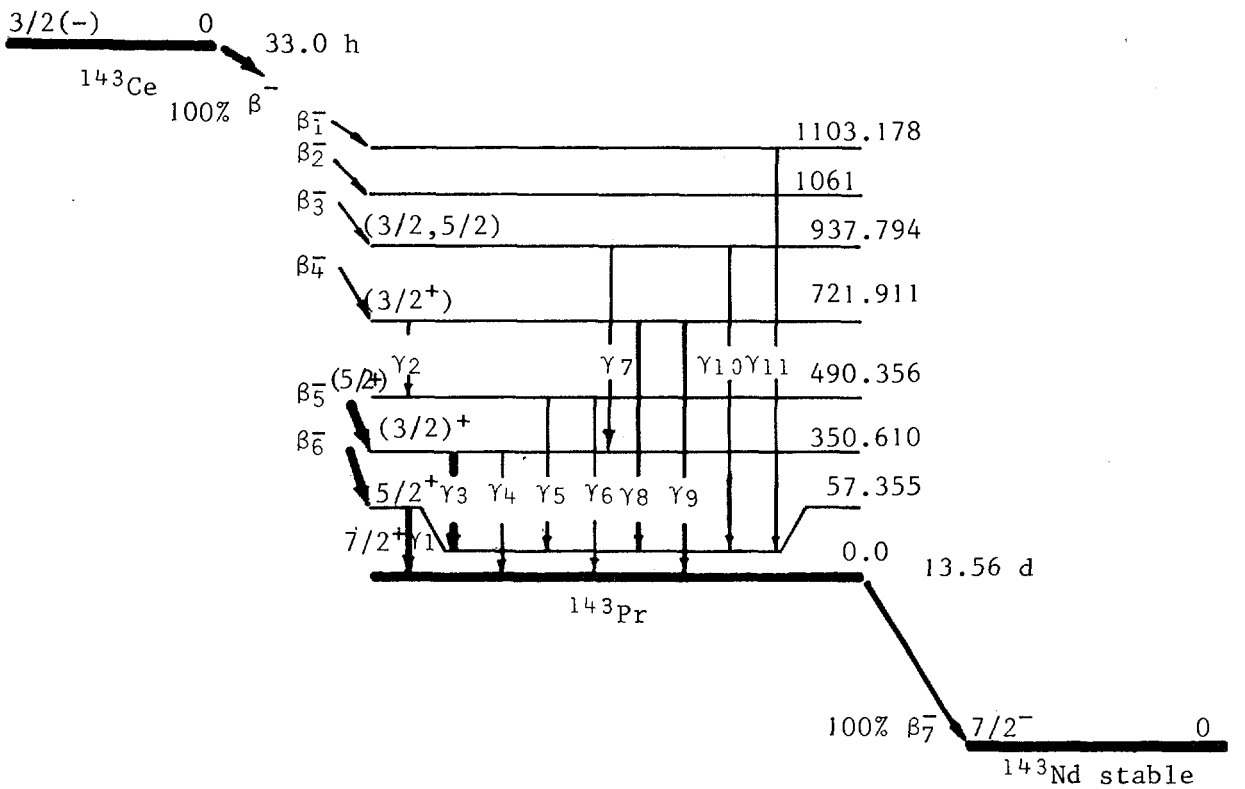
$^{139}La(n,\gamma)\ {}^{140}La(n,\gamma)\ {}^{141}La \xrightarrow{\beta^-} {}^{141}Ce$

^{143}Ce - ^{143}Pr

Diagram of radioactive decay chain

$^{143}Ce(33.0\ h)\ \beta^- \rightarrow {}^{143}Pr(13.56\ d)\ \beta^- \rightarrow {}^{143}Nd$

Disintegration scheme



Disintegration data |MED78|

^{143}Ce : half-life : $T_{\frac{1}{2}} = 33.0(2)$ h

decay constant : $\lambda = 5.8346 \times 10^{-6} s^{-1}$

β^-number	$E(\beta^-)$max.(in keV)	$E(\beta^-)$av.(in keV)	$P\beta^-$(in %)
1	294(4)	83.6(12)	0.50 (3)
2	395(4)	116.2(12)	0.152(10)
3	517(4)	158.2(13)	1.41 (8)
4	733(4)	237.4(14)	13.5 (7)
5	1104(4)	384.6(15)	49 (3))
6	1398(4)	507.5(16)	35 (5))
total β^-		402.1(17)	100 (6)

9 weak β's omitted : $E(\beta)$av = 151.4 keV $\Sigma P\beta$ = 0.24%

γ number	$E(\gamma)$(keV)	$P\gamma$ (%)
1	57.355(9)	11.7(9)
2	231.563(6)	2.09(12)
3	293.261(15)	43.4(22)
4	350.610(16)	3.25(18)
5	432.987(16)	0.161(11)
6	490.356(16)	2.16(13)
7	587.181(22)	0.269(14)
8	664.554(16)	5.8(4)
9	721.911(16)	5.5(3)
10	880.439(16)	1.05(6)
11	1103.178(25)	0.423(24)

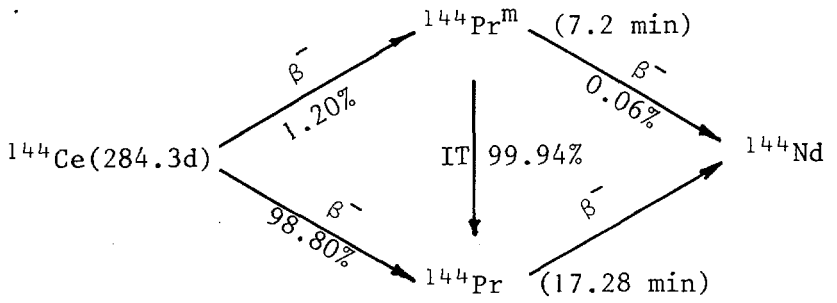
37 weak γ's omitted : $E(\gamma)$av 629.4 keV ; $\Sigma P\gamma$ = 0.68%
feeding ^{143}Pr: 100%.

^{143}Pr : half-life : $T_{\frac{1}{2}}$ = 13.56(2) d
decay constant : λ = $5.9163 \times 10^{-7} s^{-1}$

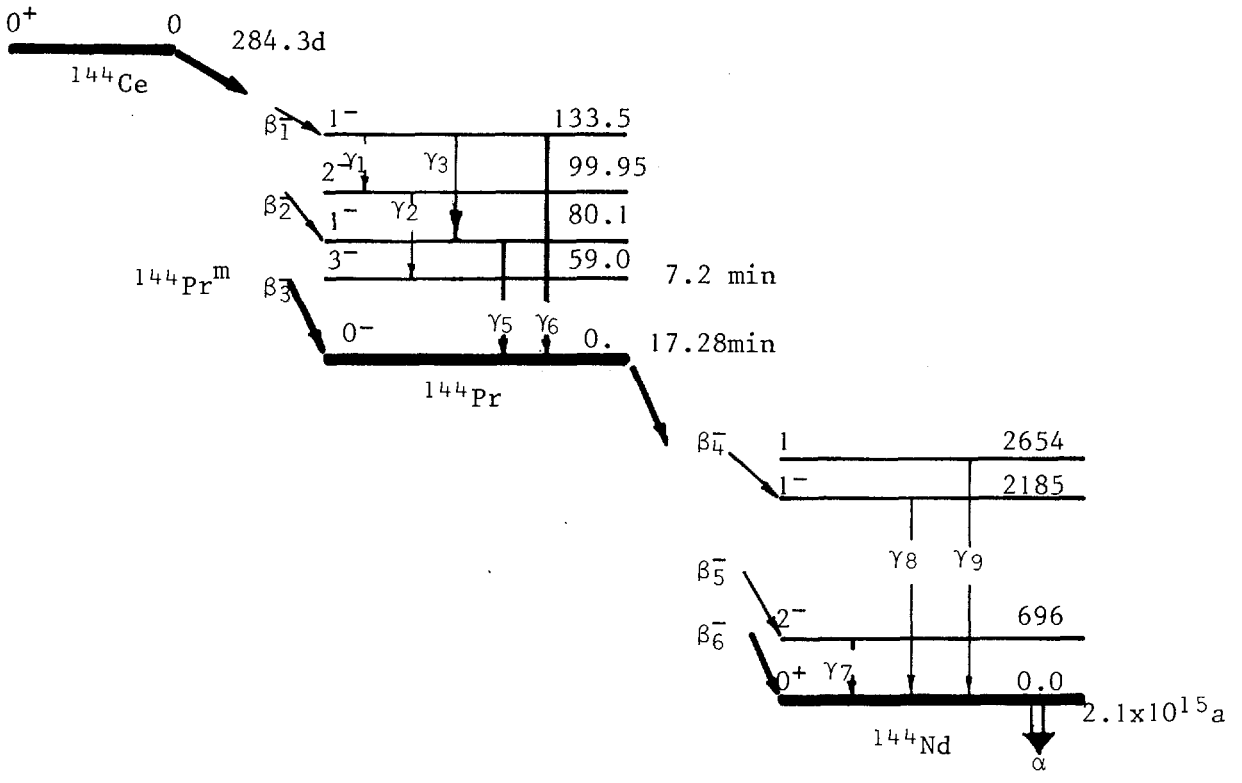
$E(\beta_7^-)$ max : 932.0(20) keV; $E(\beta_7^-)$ av = 314.3(8) keV 100%

^{144}Ce - ^{144}Pr

Diagram of radioactive decay chain



Disintegration scheme



Disintegration data [MED78]

^{144}Ce : β-decay half-life : $T_{\frac{1}{2}}$ = 284.3(3) d

decay constant : λ = $2.82156 \times 10^{-8} s^{-1}$

Percentage feeding of ^{144}Pr (17.28 min) is 98.80(8)%

Percentage feeding of $^{144}Pr^m$ (7.2 min) is 1.20(9)%

β^- number	$E(\beta^-)$ max(in keV)	$E(\beta^-)$ av(in keV)	P_β (in %)
1	181.9(15)	49.3(5)	19.6(13)
2	235.3(15)	65.3(5)	4.6(5)
3	315.4(15)	90.2(5)	75.9(12)
total β^-		81.0(6)	100.1(19)

γ number	$E(\gamma)$(in keV)	P_γ (in %)
1	33.57(3)	0.25(3)
2	40.93(3)	0.49(14)
3	53.41(5)	0.119(13)
5	80.12(3)	1.64(14)
6	133.53(3)	10.8(7) *

$^{144}Pr^m$: IT decay half-life : $T_{\frac{1}{2}}$ = 7.2(2) min

decay constant : λ = $1.605 \times 10^{-3} s^{-1}$

Percentage IT decay is 99.94%

Percentage β decay is 0.06%

The decay is mainly by electron capture and X-ray emission.

E_γ = 59.0 keV P_γ = 0.08%

^{144}Pr : β^- decay half-life : $T_{\frac{1}{2}}$ = 17.28(3) min

decay constant: λ = $6.6854 \times 10^{-4} s^{-1}$

β^- number	$E(\beta^-)$ max(in keV)	$E(\beta^-)$ av(in keV)	P_β (in %)
4	811(3)	267.0(12)	1.08(5)
5	2301(3)	894.8(14)	1.17(5)
6	2997(3)	1221.8(14)	97.75(10)
total β^-		1207.6(15)	100.01(13)

γ number	$E(\gamma)$(in keV)		P_γ (in %)
7	696.510(3)		1.48(6) *
8	1489.160(5)	|Gr79|	0.300(13)*
9	2185.662(7)		0.77(4) *

* See remark at end.

* Remark

γ-ray emission probabilities P_γ per decay reported in |De79| and |Le78,1| are :

Nuclide	E(γ)(in keV)	P_γ (in %)|De79|	P_γ (in %)|Le78,1|
^{144}Ce	133.53	11.09(16)	11.1(5)
^{144}Pr	696.510	1.342(14)	1.34(4)
	1489.160	0.279(3)	0.28(1)
	2185.662	0.700(10)	0.70(3)

For the ^{144}Ce - ^{144}Pr gamma-ray emission probabilities, values published in these two references are about 10% lower than those of |MED78|.

References

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Table 1:

Adjusted chain fission yields for ^{232}Th fission.

This table is based on data from the review paper by Cuninghame |Cu78|

fission product nuclide	fission yield values (in %) for					
	fast reactor fission			14 MeV fission		
	|Cr77|	|Me77|	|Cu78|	|Cr77|	|Me77|	|Cu78|
^{95}Zr	5.73	5.33	5.45	5.68	4.63	5.15
^{97}Zr	4.75	4.33	4.35	3.33	3.17	3.25
^{103}Ru	0.167	0.161	0.158	0.940	1.03	0.985
^{131}I	1.75	1.62	1.63	2.55	2.53	2.51
^{132}Te	2.76	2.89	2.78	3.18	2.85	3.01
^{137}Cs	6.50	6.68	5.93	6.12	5.63	5.87
^{140}Ba	7.60	7.77	7.89	5.75	5.82	5.78
^{141}Ce	7.05	7.27	7.20	5.89	6.03	5.96
^{143}Ce	6.82	6.67	6.87	4.94	5.31	5.12
^{144}Ce	7.62	7.83	7.70	3.58	4.22	3.90
^{148}Nd	2.05	2.02	2.08	1.38	0.977	1.18

Table 2:

Adjusted chain fission yields for ^{235}U fission.

This table is based on data from the review paper by Cuninghame |Cu78|

fission product nuclide	fission yield values (in %) for								
	thermal fission			fast reactor fission			14MeV fission		
	|Cr77|	|Me77|	|Cu78|	|Cr77|	|Me77|	|Cu78|	|Cr77|	|Me77|	|Cu78|
^{95}Zr	6.51	6.50	6.52	6.43	6.37	6.40	4.84	5.01	4.93
^{97}Zr	6.03	5.94	6.01	5.88	5.95	5.91	5.77	5.77	5.77
^{103}Ru	3.15	3.03	3.04	3.29	3.24	3.26	3.48	3.24	3.36
^{131}I	2.78	2.89	2.82	3.23	3.20	3.21	4.09	4.03	4.06
^{132}Te	4.29	4.29	4.24	4.63	4.61	4.62	4.29	4.64	4.46
^{137}Cs	6.22	6.23	6.24	6.18	6.17	6.17	6.15	4.84	5.49
^{140}Ba	6.31	6.31	6.34	5.95	6.11	6.03	4.42	4.56	4.49
^{141}Ce	5.81	5.84	5.84	5.93	6.01	5.97	3.91	4.34	4.12
^{143}Ce	5.94	5.95	5.94	5.74	5.70	5.72	3.93	3.92	3.92
^{144}Ce	5.38	5.49	5.43	5.34	5.27	5.30	3.09	3.20	3.15
^{148}Nd	1.67	1.67	1.67	1.68	1.67	1.67	1.20	1.25	1.23

Table 3:

Adjusted chain fission yields for ^{238}U fission.

This table is based on data from the review paper by Cuninghame |Cu78|

fission product nuclide	fission yield values (in %) for					
	fast reactor fission			14MeV fission		
	|Cr77|	|Me77|	|Cu78|	|Cr77|	|Me77|	|Cu78|
^{95}Zr	5.28	5.13	5.20	4.97	5.03	5.00
^{97}Zr	5.55	5.51	5.53	5.18	5.33	5.25
^{103}Ru	6.38	6.19	6.28	4.80	4.66	4.73
^{131}I	3.19	3.21	3.20	3.92	4.18	4.05
^{132}Te	5.11	5.18	5.14	4.65	4.91	4.78
^{137}Cs	6.04	6.01	6.03	6.14	4.87	5.50
^{140}Ba	6.07	5.94	6.01	4.62	4.68	4.65
^{141}Ce	6.76	5.38	6.07	4.42	4.41	4.41
^{143}Ce	4.68	4.53	4.60	3.70	3.94	3.82
^{144}Ce	4.65	4.52	4.58	3.80	3.70	3.75
^{148}Nd	2.13	2.08	2.11	1.87	1.73	1.80

Table 4:

Adjusted chain fission yields for the fast reactor fission for ^{237}Np fission.

This table is based on data from the review paper by Cuninghame |Cu78|

fission product nuclide	fission yield(in %)	
	|Cu78|	error
^{95}Zr	5.78	0.12
^{97}Zr	6.51	0.28
^{103}Ru	5.50	0.16
^{131}I	4.07	0.16
^{132}Te	5.30	0.33
^{137}Cs	6.08	0.33
^{140}Ba	5.58	--
^{141}Ce	6.30	0.16
^{143}Ce	4.92	0.16
^{144}Ce	4.92	0.16
^{148}Nd	--	--

Table 5:

Adjusted chain fission yields for ^{239}Pu fission

This table is based on data from the review paper by Cuninghame |Cu78|

fission product nuclide	fission yield values (in %) for						
	thermal fission			fast reactor fission			14MeV fission
	|Cr77|	|Me77|	|Cu78|	|Cr77|	|Me77|	|Cu78|	|Cu78|
^{95}Zr	4.98	4.92	4.99	4.71	4.66	4.69	3.58
^{97}Zr	5.54	5.38	5.55	5.21	5.24	5.23	4.45
^{103}Ru	6.79	6.94	6.38	6.61	6.76	6.68	5.42
^{131}I	3.78	3.85	3.77	4.12	3.86	3.99	4.77
^{132}Te	5.15	5.38	5.25	5.34	5.22	5.28	5.22
^{137}Cs	6.64	6.61	6.65	6.70	6.50	6.60	4.92
^{140}Ba	5.58	5.50	5.56	5.23	5.35	5.29	4.03
^{141}Ce	5.34	5.22	5.27	5.62	5.29	5.45	3.63
^{143}Ce	4.47	4.42	4.47	4.38	4.30	4.34	2.78
^{144}Ce	3.82	3.73	3.78	3.73	3.68	3.70	2.79
^{148}Nd	1.71	1.63	1.68	1.69	1.63	1.66	1.44

Table 6:

Cumulative fission yields of ^{235}U for a thermal neutron spectrum

The values are obtained by D.M. Gilliam et al. |Gi78| in the Interlaboratory LMFBR Reaction Rate (ILRR) program, and is based on irradiation of ^{235}U foils in the very well thermalized neutron spectrum in the thermal column of the NBS reactor.
They consider two categories of yield data:

- the socalled consensus yields, given for the fission products ^{95}Zr, ^{103}Ru and ^{140}Ba, obtained by gamma-ray measurements at INEL, ANL and HEDL, and
- the socalled subsidiary yields, for a few other fission products, which were studied less intensively (usually by only one of the participating laboratories).

The ILRR data are compared with the ENDF/B-V data (according to the status of March 1977).

principle fissionable nuclide	fission product nuclide	category*	ILRR data Y_1	ENDF/B-V data Y_2	(Y_2/Y_1-1) X 100%
^{235}U	^{95}Zr	C	0.0652 ±2.6%	0.0650	- 0.3%
	^{97}Zr	S	0.0592 ±4.1%	0.0594	0.3%
	^{103}Ru	C	0.0302 ±2.6%	0.0304	- 0.7%
	^{131}I	S	0.0286 ±4.6%	0.0289	1.0%
	^{132}Te	S	0.0421 ±6.2%	0.0429	1.9%
	^{137}Cs	C	0.0612 ±2.4%	0.0623	1.8%
	^{140}Ba	C	0.0622 ±2.3%	0.0629	1.1%
	^{141}Ce	S	0.0572 ±5.5%	0.0584	2.1%
	^{143}Ce	S	0.0536 ±9.2%	0.0595	11.0%
	^{144}Ce	S	0.0572 ±2.9%	0.0549	- 4.2%

* S means subsidiary yield
C means consensus yield

Table 7 :

Cumulative fission yields for a fast reactor spectrum

The values are obtained by D.M. Gilliam et al. |Gi78| in the Interlaboratory LMFBR Reaction Rate (ILRR) program, and are based upon irradiations in BIG-10 and CFRMF.

They consider two categories of yield data :

- the so-called consensus yields, given for the fission products ^{95}Zr, ^{103}Ru and ^{140}Ba, obtained by gamma-ray measurements at INEL, ANL and HEDL, and
- the so-called subsidiary yields, for a few other fission products, which were studied less intensively (usually by only one of the participating laboratories).

The ILRR data are compared with the ENDF / B-V data (according to the status of March 1977).

Cumulative fission yields for a fast reactor spectrum

principle fissionable nuclide	fission product nuclide	category*	ILRR data Y_1	ENDF/B-V data Y_2	(Y_2/Y_1-1) X 100%
^{235}U	^{95}Zr	C	0.0645 ±2.2%	0.0638	- 1.1%
	^{97}Zr	S	0.0603 ±2.4%	0.0594	- 1.5%
	^{103}Ru	C	0.0333 ±2.3%	0.0327	- 1.8%
	^{131}I	S	0.0331 ±4.3%	0.0320	- 3.3%
	^{132}Te	S	0.0483 ±6.1%	0.0457	- 5.4%
	^{137}Cs	S	0.0626 ±5.8%	0.0617	- 1.4%
	^{140}Ba	C	0.0610 ±1.9%	0.0610	0.0%
	^{143}Ce	S	0.0517 ±8.7%	0.0570	10.3%
	^{144}Ce	S	0.0583 ±4.5%	0.0527	- 9.6%
^{238}U	^{95}Zr	C	0.0519 ±2.6%	0.0514	- 1.0%
	^{97}Zr	S	0.0568 ±3.0%	0.0550	- 3.2%
	^{103}Ru	C	0.0634 ±2.5%	0.0624	- 1.6%
	^{131}I	S	0.0326 ±4.3%	0.0321	- 1.5%
	^{137}Cs	S	0.0600 ±4.5%	0.0600	0%
	^{140}Ba	C	0.0600 ±2.2%	0.0595	- 0.8%
	^{143}Ce	S	0.0421 ±8.7%	0.0453	7.6%
	^{144}Ce	S	0.0495 ±4.3%	0.0451	- 8.9%
^{239}Pu	^{95}Zr	C	0.0480 ±2.3%	0.0467	- 2.7%
	^{97}Zr	S	0.0544 ±2.5%	0.0522	- 4.0%
	^{103}Ru	C	0.0708 ±2.3%	0.0686	- 3.1%
	^{132}Te	S	0.0544 ±6.1%	0.0503	- 7.5%
	^{137}Cs	S	0.0676 ±2.6%	0.0651	- 3.7%
	^{140}Ba	C	0.0531 ±2.0%	0.0536	0.9%
	^{143}Ce	S	0.0390 ±8.7%	0.0430	10.3%
	^{144}Ce	S	0.0379 ±5.5%	0.0368	- 2.9%
^{237}Np	^{95}Zr	C	0.0593 ±4.0%	0.0585	- 1.3%
	^{97}Zr	S	0.0683 ±3.8%	0.0612	- 4.1%
	^{103}Ru	C	0.0589 ±4.3%	0.0583	- 1.0%
	^{137}Cs	S	0.0650 ±5.2%	0.0618	- 4.9%
	^{140}Ba	C	0.0574 ±3.6%	0.0548	- 4.5%

* S means subsidiary yield
C means consensus yield

Table 8:

HFR SPECTRUM.

NEUTRON FLUX DENSITIES FOR ABBNGROUPS

GROUP.	ENERGY REGION (IN MEV)	GROUP FLUX DENSITY (M-2.S-1)	PHI(U) REL.
1	1.050E+01... 6.500E+00	4.121E+15	1.198E-02
2	6.500E+00... 4.000E+00	2.043E+16	5.869E-02
3	4.000E+00... 2.500E+00	4.611E+16	1.368E-01
4	2.500E+00... 1.400E+00	7.911E+16	1.903E-01
5	1.400E+00... 8.000E-01	7.095E+16	1.768E-01
6	8.000E-01... 4.000E-01	7.476E+16	1.504E-01
7	4.000E-01... 2.000E-01	5.617E+16	1.130E-01
8	2.000E-01... 1.000E-01	4.363E+16	8.779E-02
9	1.000E-01... 4.650E-02	3.451E+16	6.286E-02
10	4.650E-02... 2.150E-02	2.458E+16	4.443E-02
11	2.150E-02... 1.000E-02	2.072E+16	3.775E-02
12	1.000E-02... 4.650E-03	1.948E+16	3.548E-02
13	4.650E-03... 2.150E-03	1.856E+16	3.356E-02
14	2.150E-03... 1.000E-03	1.806E+16	3.290E-02
15	1.000E-03... 4.650E-04	1.781E+16	3.244E-02
16	4.650E-04... 2.150E-04	1.767E+16	3.195E-02
17	2.150E-04... 1.000E-04	1.729E+16	3.151E-02
18	1.000E-04... 4.650E-05	1.708E+16	3.110E-02
19	4.650E-05... 2.150E-05	1.694E+16	3.062E-02
20	2.150E-05... 1.000E-05	1.655E+16	3.015E-02
21	1.000E-05... 4.650E-06	1.640E+16	2.987E-02
22	4.650E-06... 2.150E-06	1.655E+16	2.993E-02
23	2.150E-06... 1.000E-06	1.647E+16	3.000E-02
24	1.000E-06... 4.650E-07	1.649E+16	3.004E-02
25	4.650E-07... 2.150E-07	1.660E+16	3.002E-02

TOTAL FOR 25 ABBN GROUPS 7.171E+17

NEUTRON FLUX DENSITIES FOR SPECIAL ENERGY GROUPS

E > 10.5 MEV	:	2.663E+14
E > 1.0 MEV	:	1.934E+17
E > 0.1 MEV	:	3.953E+17
E < 0.215 EV	:	1.087E+17
T O T A L	=	8.261E+17

SPECTRUM CHARACTERISTICS

AVERAGE ENERGY = 6.966E-01 MEV
AVARAGE SPEED = 1.700E+04 M.S-1
AVERAGE LETHARGY= 7.794E+00

PHI(NI) = 2.419E+17 M-2.S-1
PHI(FE) = 2.375E+17 M-2.S-1
PHI(CO) = 1.433E+17 M-2.S-1

DAMAGE TO ACTIVATION RATIO (D A R).

	GRAPHITE	STEEL	ALUMINIUM
NI58(N,P)CO58	1.65E+00	1.30E+00	1.44E+00
FE54(N,P)MN54	1.64E+00	1.29E+00	1.43E+00

Table 9:

CTR SPECTRUM (TOKAMAK) REF |DI79|

NEUTRON FLUX DENSITIES FOR ABBNGROUPS

GROUP.	ENERGY REGION (IN MEV)	GROUP FLUX DENSITY (M-2.S-1)	PHI(U) REL
1	1.050E+01... 6.500E+00	2.306E+02	6.376E-02
2	6.500E+00... 4.000E+00	2.553E+02	6.972E-02
3	4.000E+00... 2.500E+00	3.223E+02	9.093E-02
4	2.500E+00... 1.400E+00	4.570E+02	1.045E-01
5	1.400E+00... 8.000E-01	7.320E+02	1.734E-01
6	8.000E-01... 4.000E-01	1.150E+03	2.200E-01
7	4.000E-01... 2.000E-01	1.131E+03	2.164E-01
8	2.000E-01... 1.000E-01	8.790E+02	1.681E-01
9	1.000E-01... 4.650E-02	8.052E+02	1.394E-01
10	4.650E-02... 2.150E-02	6.436E+02	1.106E-01
11	2.150E-02... 1.000E-02	4.400E+02	7.622E-02
12	1.000E-02... 4.650E-03	2.278E+02	3.944E-02
13	4.650E-03... 2.150E-03	1.428E+02	2.454E-02
14	2.150E-03... 1.000E-03	6.555E+01	1.135E-02
15	1.000E-03... 4.650E-04	8.124E+00	1.407E-03
16	4.650E-04... 2.150E-04	3.485E+01	5.990E-03
17	2.150E-04... 1.000E-04	1.290E+01	2.235E-03
18	1.000E-04... 4.650E-05	3.504E+00	6.068E-04
19	4.650E-05... 2.150E-05	2.500-101	4.297-105
20	2.150E-05... 1.000E-05	1.150-101	1.992-105
21	1.000E-05... 4.650E-06	5.350-102	9.264-106
22	4.650E-06... 2.150E-06	2.500-102	4.297-106
23	2.150E-06... 1.000E-06	1.150-102	1.992-106
24	1.000E-06... 4.650E-07	5.350-103	9.264-107
25	4.650E-07... 2.150E-07	2.500-103	4.297-107

TOTAL FOR 25 ABBN GROUPS 7.542E+03

NEUTRON FLUX DENSITIES FOR SPECIAL ENERGY GROUPS

E > 10.5 MEV	:	2.535E+03
E > 1.0 MEV	:	4.253E+03
E > 0.1 MEV	:	5.157E+03
E < 0.215 EV	:	2.149-103
T O T A L	=	1.008E+04

SPECTRUM CHARACTERISTICS

AVERAGE ENERGY = 4.293E+00 MEV PHI(NI) = 1.259E+04 M-2.S-1
AVARAGE SPEED = 4.841E+06 M.S-1 PHI(FE) = 1.495E+04 M-2.S-1
AVERAGE LETHARGY= 2.752E+00 PHI(CO) = 2.390E+01 M-2.S-1

DAMAGE TO ACTIVATION RATIO (D A R).

	GRAPHITE	STEEL	ALUMINIUM
NI58(N.P)CO58	6.20E-01	7.95E-01	6.07E-01
FE54(N.P)MN54	5.11E-01	6.55E-01	5.00E-01

Table 10 :

Means of Percentage Errors in Fission Yields (1σ) Shown in Some of the Evaluations Considered for the 1973 and 1977 FPND Panels *

Fissile Nuclide	Fission Energy	Section of Mass Yield Curve	Mass Range	Mean of Percentage Errors Reported (1σ)				Suggested 1977 1σ Errors
				Crouch 1973	Meek and Rider 1973	Crouch 1977	Meek and Rider 1977	
^{235}U	Thermal	Light wing	72–84	10.9	15.1	20.5	17.6	19.0
		Light peak	85–104	3.4	1.0	2.7	0.9	1.8
		Valley	105–129	3.7	10.8	16.9	9.6	13.2
		Heavy peak	130–150	1.8	1.1	2.8	1.2	2.0
		Heavy wing	151–161	5.6	8.7	8.2	7.9	8.1
^{239}Pu	Thermal	Light wing	72–87	8.3	15.2	16.2	15.6	15.9
		Light peak	88–109	5.4	3.9	8.2	3.6	5.9
		Valley	110–129	11.7	13.8	17.4	15.1	16.2
		Heavy peak	130–150	5.1	1.7	6.2	1.2	3.7
		Heavy wing	151–161	11.3	9.1	13.5	8.8	11.1
^{235}U	Fast (pile)	Light wing	72–83	–	20.6	18.4	21.2	19.8
		Light peak	84–105	3.8	1.9	5.2	1.4	3.3
		Valley	106–129	10.1	9.3	17.0	10.1	13.5
		Heavy peak	130–150	3.4	1.8	3.8	1.4	2.6
		Heavy wing	151–161	11.3	12.6	15.3	12.2	13.7
^{238}U	Fast (pile)	Light wing	72–85	–	19.6	18.5	18.3	18.4
		Light peak	86–106	8.3	8.4	7.4	3.2	5.3
		Valley	107–129	16.9	13.0	20.5	11.4	16.0
		Heavy peak	130–150	8.6	3.9	6.0	1.8	3.9
		Heavy wing	151–161	13.0	10.7	15.5	9.0	12.2
^{239}Pu	Fast (pile)	Light wing	72–86	9.3	16.4	21.5	11.5	15.5
		Light peak	87–109	5.9	4.1	7.3	2.4	4.9
		Valley	110–129	24.1	10.1	22.1	9.6	15.8
		Heavy peak	130–150	4.7	3.1	4.9	1.6	3.3
		Heavy wing	151–161	8.2	9.8	12.6	8.2	10.4
^{235}U	14 MeV	Light wing	72–83	12.5	21.4	17.0	10.2	13.6
		Light peak	84–110	10.8	9.0	15.5	6.5	11.0
		Valley	111–129	13.6	9.6	16.1	7.8	12.0
		Heavy peak	130–150	8.0	8.4	12.3	5.7	9.0
		Heavy wing	151–161	9.2	14.9	16.0	9.0	12.5

* Reproduced from |Cu78|; the word 'error' should be interpreted as 'uncertainty'.

Table 11 :

Percentage Errors in Fission Yields (1σ) of Certain Important Nuclides Given in Some of the Evaluations Considered for the 1973 and 1977 FPND Panels *

Fissile Nuclide	Fission Energy	Evaluation	Percentage Errors Reported (1σ) for mass:-							
			95	103	106	133	137	140	141	Mean for:- 143, 144, 145 146, 148, 150
^{235}U	Thermal	Crouch 1973	2.0	6.0	12.0	0.5	1.0	0.5	3.0	1.4
		M & R 1973	0.7	2.0	1.4	0.5	0.5	0.5	1.4	0.5
		Crouch 1977	1.6	6.4	6.6	2.8	1.3	1.2	1.9	1.2
		M & R 1977	0.7	1.4	1.4	0.5	0.35	0.5	1.0	0.4
Suggested 1977 1σ error			1.1	3.9	4.0	1.6	0.8	0.9	1.5	0.8
^{239}Pu	Thermal	Crouch 1973	5.0	7.0	4.0	3.0	6.0	5.0	4.0	5.5
		M & R 1973	2.0	2.8	2.8	1.4	1.0	1.0	2.8	0.7
		Crouch 1977	2.9	4.3	3.8	9.5	2.9	5.9	3.3	7.0
		M & R 1977	2.0	2.0	2.8	0.7	0.5	1.0	2.8	0.5
Suggested 1977 1σ error			2.5	3.2	3.3	5.1	1.7	3.5	3.0	3.8
^{235}U	Fast (pile)	Crouch 1973	2.5	5.5	27.0	3.0	5.5	2.0	3.0	3.2
		M & R 1973	1.0	2.0	6.0	1.4	1.0	1.4	2.0	1.1
		Crouch 1977	1.8	2.6	27.4	2.3	4.6	1.5	2.7	2.5
		M & R 1977	1.0	1.4	6.0	1.4	0.7	0.7	2.0	0.8
Suggested 1977 1σ error			1.4	2.0	15.7	1.8	2.7	1.1	2.4	1.6
^{238}U	Fast (pile)	Crouch 1973	6.0	13.0	9.0	-	7.0	2.5	-	9.7
		M & R 1973	2.8	2.8	8.0	2.8	4.0	2.0	8.0	2.3
		Crouch 1977	4.3	8.4	7.7	6.1	5.6	2.1	20.0	4.6
		M & R 1977	1.4	2.0	4.0	1.4	1.0	1.4	2.8	1.1
Suggested 1977 1σ error			2.9	4.2	5.8	3.8	3.3	1.7	11.4	2.9
^{239}Pu	Fast (pile)	Crouch 1973	3.0	4.5	10.0	5.0	10.0	1.5	4.0	3.8
		M & R 1973	2.0	2.0	6.0	2.0	2.0	1.4	4.0	1.6
		Crouch 1977	3.3	6.4	10.3	3.3	8.6	1.9	3.6	3.5
		M & R 1977	1.4	2.0	2.8	1.4	0.7	1.0	2.8	0.8
Suggested 1977 1σ error			2.4	4.2	6.6	2.3	4.7	1.4	3.2	2.2
^{235}U	14 MeV	Crouch 1973	9.0	7.0	20.0	10.0	10.0	5.0	10.0	-
		M & R 1973	6.0	4.0	6.0	6.0	2.8	4.0	8.0	11.0
		Crouch 1977	7.6	5.7	17.6	11.7	10.0	2.6	10.0	15.0
		M & R 1977	6.0	4.0	4.0	6.0	2.8	2.8	6.0	7.8
Suggested 1977 1σ error			6.8	4.9	10.8	8.8	6.4	2.7	8.0	11.4

* Reproduced from |Cu78|; the word 'error' should be interpreted as 'uncertainty'.

Table 12:

Data set for selected fission products with half-lives longer than one day.

The following lists are part of a computerized data set in current use at the PTB for the calculation of decay heat, burn-up, fission product activities and breeded plutonium.
The fission yield values are valid for the thermal fission of ^{235}U and ^{239}Pu respectively.
In some cases gamma-ray energies with small emission probability were condensed to simplify matters.
This data set should be regarded as an attempt to test necessity and utility of further fission product nuclide data. In this context one should realize that data in these lists may not always be fully consistent with data presented elsewhere in this guide.

Table 12a: Half-lives and fission yields for selected fission products.

Table 12b: Gamma-ray energies for selected fission products.

Table 12a: Half-lives and fission yields for selected fission products.

nuclide	state	$T_{\frac{1}{2}}$ (in d)	thermal fission yield for	
			^{235}U (in %)	^{239}Pu (in %)
^{85}Kr	p	3.923×10^{3}	1.32	0.558
^{89}Sr	p	5.052×10^{1}	4.75	1.72
^{90}Sr	p	1.027×10^{4}	5.84	2.12
^{90}Y	d	2.67	5.84	2.12
^{91}Sr	o	3.950×10^{-1}	5.81	2.44
^{91}Y	d	5.860×10^{1}	5.89	2.44
^{95}Zr	p	6.550×10^{1}	6.50	4.98
^{95}Nb	d	3.510×10^{1}	6.50	4.98
^{99}Mo	p	2.75	6.13	6.19
$^{99}Tc^{m}$	d	2.500×10^{-1}	6.13	6.19
^{103}Ru	p	3.960×10^{1}	3.09	6.79
$^{103}Rh^{m}$	d	4.000×10^{-2}	3.09	6.79
^{106}Ru	p	3.689×10^{2}	0.393	4.29
^{106}Rh	d	3.500×10^{-4}	0.393	4.29
^{111}Ag	p	7.47	0.019	0.267
$^{115}Cd^{m}$	p	4.480×10^{1}	0.010	0.038
^{125}Sn	p	9.65	0.029	0.116
^{125}Sb	p	9.971×10^{2}	0.029	0.116
$^{125}Te^{m}$	d	5.800×10^{1}	0.007	0.038
$^{127}Te^{m}$	p	1.090×10^{2}	0.018	0.083
$^{129}Te^{m}$	p	3.340×10^{1}	0.080	0.216
^{131}I	p	8.04	2.78	3.78
^{132}Te	p	3.25	4.28	5.15
^{132}I	d	9.500×10^{-2}	4.28	5.15
^{133}Xe	p	5.29	6.67	6.95
^{133}Cs	d	1.000×10^{7}*	6.67	6.95
^{134}Cs	d_2	7.561×10^{2}	6.67	6.95
^{136}Cs	p	1.300×10^{1}	0.007	0.101
^{137}Cs	p	1.100×10^{4}	6.21	6.64
^{140}Ba	p	1.279×10^{1}	6.30	5.58
^{140}La	d	1.67	6.30	5.58
^{141}Ce	p	3.251×10^{1}	5.78	5.34
^{143}Ce	p	1.38	5.93	4.47
^{143}Pr	d	1.358×10^{1}	5.93	4.47
^{144}Ce	p	2.844×10^{2}	5.37	3.82
^{144}Pr	d	1.200×10^{-2}	5.37	3.82
^{147}Pr	p	1.098×10^{1}	2.30	2.11
^{147}Pm	d	9.570×10^{2}	2.30	2.11
$^{148}Pm^{m}$	d_2	4.130×10^{1}	1.67	1.68
^{156}Eu	p	1.517×10^{1}	0.013	0.011

p = parent nuclide;
d = daughter nuclide in first generation;
d_2= daughter nuclide in second generation.

*This value approximates the stability of ^{133}Cs.

Table 12b: Gamma-ray energies for selected fission products.

nuclide	gamma-ray energies (in keV) and effective gamma-ray emission probabilities (in %)			
^{85}Kr	514.0 0.43.			
^{91}Sr	274.2 1.17;	555.6 56.0 ;	620.1 1.85;	652.9 11.4 ;
	749.7 22.4 ;	925.7 4.0 ;	1024.0 34.1 ;	1281.0 0.95;
	1413.0 1.02;	1652.0 0.29.		
^{91}Y	1208.0 0.22.			
^{95}Zr	724.3 44.4 ;	756.7 54.6 .		
^{95}Nb	765.8 100 .			
^{99}Mo	40.6 1.17;	181.9 6.0 ;	366.4 1.21;	739.5 12.3 ;
	777.9 4.37.			
$^{99}Tc^{m}$	140.5 88.96.			
^{103}Ru	39.8 0.07;	53.3 0.31;	294.9 0.27;	443.8 0.35;
	497.1 89.40;	557.1 0.80;	610.4 5.72.	
^{106}Rh	512.0 20.50;	616.0 0.74;	622.0 9.95;	873.0 0.42;
	1050.0 1.45;	1128.0 0.38;	1562.0 0.15.	
^{111}Ag	96.3 0.31;	245.5 1.50;	342.1 7.30.	
$^{115}Cd^{m}$	158.1 0.02;	484.4 0.31;	933.6 2.05;	1291.0 0.92;
	1449.0 0.02.			
^{125}Sn	332.0 1.35;	469.7 1.27;	800.5 0.99;	822.6 3.91;
	915.5 4.25;	1067.0 8.86;	1087.0 1.09;	1089.0 4.20;
	1420.0 0.42;	2002.0 2.00.		
^{125}Sb	35.5 5.97;	81.8 1.00;	116.9 0.33;	176.3 6.74;
	204.1 0.30;	321.0 0.43;	380.4 1.50;	427.9 29.70;
	443.5 0.30;	463.4 10.5 ;	489.8 0.25;	600.6 18.0 ;
	606.7 4.93;	636.0 11.4 ;	671.5 1.75.	
$^{125}Te^{m}$	35.5 5.97;	109.3 0.28.		
$^{127}Te^{m}$	57.6 0.39;	88.3 0.08;	658.9 0.01.	
$^{129}Te^{m}$	696.0 3.23;	729.6 0.77;	1084.0 0.61.	
^{131}I	80.2 2.45;	177.2 0.27;	284.3 5.80;	325.8 0.28;
	364.5 82.4 ;	639.9 6.90;	643.0 1.63;	722.9 1.63.
^{132}Te	49.7 14.6 ;	111.8 1.10;	116.3 1.20;	228.2 88.0 ;
	667.8 6.0 .			
^{132}I	262.7 1.44;	505.9 5.04;	522.7 16.10;	547.1 1.25;
	621.2 1.58;	630.2 13.7 ;	650.6 2.67;	667.7 98.7 ;
	669.8 4.94;	671.6 5.23;	727.0 2.17;	727.2 3.16;
	772.6 76.2 ;	780.2 1.23;	809.8 2.86;	812.2 5.63;
	876.8 1.08;	954.6 18.1 ;	1136.0 2.96;	1143.0 1.38;
	1173.0 1.09;	1291.0 1.14;	1372.0 2.48;	1399.0 7.11;
	1443.0 1.42;	1921.0 1.18;	2002.0 1.09;	1295.0 1.97;
^{133}Xe	79.6 0.22;	81.0 37.10;	160.6 0.06;	
^{134}Cs	475.3 1.49;	563.2 8.40;	569.4 15.0 ;	604.6 97.5 ;
	795.8 85.1 ;	802.1 8.80;	1038.0 1.02;	1168.0 1.88;
	1365.0 3.20.			
^{136}Cs	31.8 2.00;	32.2 4.00;	36.4 1.00;	66.9 12.5 ;
	86.3 6.31;	109.7 0.41;	153.2 7.47;	163.9 4.61;
	166.5 0.63;	176.6 13.5 ;	187.3 0.60;	273.7 12.7 ;
	319.9 0.60;	340.6 46.8 ;	507.2 0.98;	818.5 99.7 ;
	1048.0 79.7 ;	1235.0 19.8 .		
^{137}Cs	661.6 85.14.			

Table 12b continued.

nuclide	gamma-ray energies (in keV) and effective gamma-ray emission probabilities (in %)			
^{140}Ba	13.8 1.29;	30.0 14.0 ;	162.6 6.21;	177.0 0.19;
	304.8 4.30;	423.8 3.15;	437.6 1.93;	466.0 0.21;
	498.0 0.40;	512.0 0.26;	537.3 24.4 ;	602.0 0.60;
	637.0 0.30;	661.0 0.70.		
^{140}La	131.1 0.52;	242.0 0.47;	266.6 0.45;	328.8 20.7 ;
	432.5 2.99;	487.0 45.9 ;	751.8 4.41;	815.9 23.6 ;
	867.9 5.59;	919.6 2.68;	925.2 7.05;	951.4 0.54;
	1597.0 95.4 ;	2010.0 0.43;	2348.0 0.85;	2522.0 3.43.
^{141}Ce	145.4 48.1 .			
^{143}Ce	57.4 11.6 ;	231.6 1.98;	293.3 41.3 ;	350.6 3.30;
	433.0 0.13;	490.4 1.94;	587.3 0.24;	664.6 5.16;
	721.9 5.04;	880.4 0.91;	1103.0 0.36.	
^{144}Ce	33.6 0.24;	40.9 0.25;	80.1 1.60;	134.0 11.09.
^{144}Pr	675.7 0.61;	696.0 1.34;	1389.0 0.07;	1489.0 0.28;
	2186.0 0.70.			
^{147}Nd	91.0 27.2 ;	196.6 0.20;	120.5 0.35;	275.4 0.72;
	319.4 1.83;	398.1 0.33;	410.5 23.0 ;	439.8 1.13;
	531.0 13.1 ;	594.8 0.30;	685.9 0.76.	
$^{148}Pr^{m}$	75.7 1.09;	98.4 3.77;	189.6 1.22;	210.0 1.90;
	287.9 12.2 ;	311.5 3.91;	414.1 18.3 ;	432.6 5.58;
	501.3 6.79;	550.2 94.2 ;	599.5 12.2 ;	611.3 5.46;
	629.9 87.8 ;	725.7 32.3 ;	915.1 18.69;	1014.0 20.10.
^{156}Eu	89.0 8.96;	599.5 2.24;	646.3 6.70;	709.9 0.91;
	723.5 5.75;	811.8 10.3 ;	865.9 0.16;	944.4 1.38;
	961.0 0.15;	1065.0 5.18;	1079.0 4.35;	1153.0 7.06;
	1154.0 5.21;	1231.0 8.63;	1242.0 7.12;	1277.0 3.12;
	1366.0 1.75;	1877.0 1.67;	1937.0 2.07;	1965.0 4.14;
	2026.0 3.49;	2098.0 4.10;	2181.0 2.40;	2187.0 3.64;
	2270.0 1.09.			
^{239}Np	106.1 21.10;	209.8 3.00;	228.2 9.50;	277.6 12.10;
	285.4 0.65;	315.9 1.37;	334.2 1.71.	

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Part II: Fission reactions

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Part I lists numerical data on activation detector materials, on detection reactions involved, and on radionuclides produced.

The data are mainly taken from existing evaluations. Where evaluations were missing, unknown or obsolete, data were taken from recent literature. The detection reactions considered were selected on the basis of available information of its use for reactor neutron measurements.

In the opinion of the Euratom Working Group on Reactor Dosimetry (EWGRD) this document may contribute to the creation of a common data set for all laboratories working in the field of reactor neutron metrology.

Part II lists numerical data on fission reactions, the cross-section data and the decay data of some fission product radionuclides, suitable for gamma ray counting. The selection of data is based on the usefulness to determine neutron flux densities, neutron fluences and neutron spectra.

The data are mainly taken from existing review papers and evaluations.

It is expected that after one or two years an updated and revised guide will be issued.

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