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STICHTING
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Note to : Participants JEF-2 meeting November 14, 1988

From : H. Gruppelaar, H. A. J. van der Kamp, J. Kopecky, D. Nierop

Subject : Status Ni- evaluation

C O N C E P T

Status of the JEF-2/EFF-2 evaluation for the Ni-isotopes

1. Introduction

For the re-evaluation of the cross-sections for Ni the following decisions were made at previous meetings:

a. The evaluations will be made only for the natural Ni-isotopes; not for elemental Ni (some evaluation should also be made for Ni-59). The data will be stored in ENDF-VI format. From its large number of options only those applied in the EFF-1 lead evaluation will be adopted for Ni-58 and Ni-60.

b. For the major isotopes (Ni-58, Ni-60) the resolved-resonance parameters of H. Derrien will be adopted. At energies above 1 MeV the evaluation of M. Uhl (IRK, Vienna) will be used. In the intermediate energy range from about 500 to 600 keV upto 1 MeV ECN supplies the evaluation, using the optical model parameters of Uhl and the average statistical parameters of Derrien. The evaluation of Uhl will be reformatted at ECN.

c. For the remaining isotopes of Ni the JENDL-2 evaluations will be used, after replacing the resolved-resonance parameters with those of Derrien.

d. Only for Ni-58 and Ni-60 energy-angle distributions will be given in file 6.

e. The natural element cross-sections will be constructed only for checking with the experimental data and only for file 3.

f. The photon-production files for Ni-58 and Ni-60 will be constructed at

ECN; for the remainig Ni-isotopes the photon-production spectra for natural Ni will be used.

g. The covariance files will be constructed after completion of the evaluation; in fact only the covariance data for the natural element are relevant.

The present status is that points a through d have almost been completed. It is expected that before the end of this year a data file for all Ni isotopes, still without photon-production spectra and covariance data, can be sent to the NEA Data Bank for extensive testing and for calculation of neutron transport cross-sections in a multi-group structure. Meanwhile, work the evaluation of photon-production cross-sections and covariance data should be initiated in order to complete the evaluation before summer 1989.

In the following a detailed status report is given for each MF subfile.

1. MF1 (general information)

The descriptive text will be added at the end of the evaluation, taking into account existing information from the files of H. Derrien, M. Uhl, the JENDL-2 information and new information from ECN.

2. MF2 (resolved-resonance parameters)

The resolved-resonance parametrs of H. Derrien have been inserted into the JENDL-2 file by the NEA Data Bank. These parameters are based upon the multi-level Breit-Wigner formula for all Ni-isotopes. The NEA Data Bank has also calculated point-wise cross-sections, thermal values, resonance integrals and has provided plots of averaged cross-sections (histograms) calculated from the resonance parameters.

At ECN the work has concentrated on Ni-58 and Ni-60. The Japanese parts of these libraries have been removed and replaced by data from ECN and M. Uhl. The thermal values and capture resonance integrals were found to be in fair agreement with the recommended data given in the latest Brookhaven compilation (table 1). Some small adjustments of the negative resonance parameters may be necessary.

It was decided to use all resonance parameters given by Derrien, and to adopt E_H = 550 keV as prescribed by H. Derrien. A correction was made to compensate for the loss of (n,γ) cross-section at the high-energy end of the resolved-resonance region. This correction is based upon a statistical method, discussed in STEK-memo-144 and 148 (also JEF/Doc-...). The method was mainly used to determine the shape of the correction function, that is given in file MF-3. The absolute magnitude of the correction was slightly decreased in order to obtain corrected cross-sections in agreement with the sparse experimental data (averaged capture cross-sections) for Ni-58, Ni-60 and natural Ni. A second reason for this adjustment was the argument that there should be a no large differences in the broad group constants above and below the deviding energy E_H.

The adopted smooth correction functions for Ni-58 and Ni-60 are shown in Figs. 1 and 2, respectively. For Ni-58 a quite large correction was necessary in the range above 250 keV; a much smaller correction was required for Ni-60. We believe that the above correction method is adequate, altough there is the possibillity that already some implicit corrections are present in the resolved resonance parameters, e.g. when the radiative widths have been overestimated. This is the main justification for the above-mentioned decrease of the correction function. The large difference in the corrections for Ni-58 and Ni-60 are difficult to explain. Apperently (according to the statistical analysis) the detection limit for the Ni-60 measurement was somewhat lower at high energies than that for Ni-58.

The corrected cross-sections for (n,γ) are somewhat higher than in most evaluations, leading to a higher cross-section for natural Ni at about 850 keV, still in agreement with the experimental low-resolution data, see Fig. 3.

For the other stable Ni-isotopes the calculated values of the thermal values and resonance integrals are in good agreement with the data (table 1).

No corrections were made to the elastic scattering cross-section. The missing strength is relatively small, due to the contribution of the potential scattering and strong s-wave resonances.

3. MF3 (smooth cross-sections)

For Ni-58 and Ni-60 the following cross-sections were explicitly calculated by M. Uhl: σ_{el}, $\sigma^{discr}(n,n')$, $\sigma^{discr}(n,p)$, $\sigma^{discr}(n,\alpha)$. All continuum emission cross-sections were combined in MT=5 with yields for each individual reaction product in file MF6. At ECN a code was written to reconstruct the various reaction cross-sections, e.g. $\sigma(n,2n)$, $\sigma(n,p)$, $\sigma(n,np)$, $\sigma(n,\alpha)$, etc. Note it was not possible to distinguish between $\sigma(n,d)$ and $\sigma(n,nd)$, thus the sum of these cross-sections is given in file MF3.

The (n,γ) reaction cross-sections for Ni-58 and Ni-60 were completely re-evaluated at ECN, taking into account the optical-model used by Uhl (at least upto 5 MeV) and average resonance parameters taken from Derrien, with, however, some adjustments. At high energies a direct-collective term was added. The cross-sections initially calculated with the average parameters taken from Derrien were too high. A decrease was necessary in order to obtain agreement with existing capture data and the cross-sections calculated from the resonance parameters, see Figs. 1 and 2. This decrease was obtained by adjusting the values of D_{obs} and Γ_γ. The finally adopted parameters are still within the error margins and agree quite well with the earlier evaluation of Fröhner, used in JEF-1; see table 2. There are very few experimental data in the range near 1 MeV. The adopted cross-sections for Ni-58, Ni-60, but also for natural Ni are in reasonably good agreement with these data. Note that a smooth background cross-section was added at energies below E_H, see Sect. 3.

From the same evaluation procedure the elastic scattering cross-section was obtained upto 1 MeV. At higher energies these cross-sections were already available from the work of Uhl. There is a smooth connection between the two parts, mainly because the same optical model was adopted.

No other reactions than elastic scattering and radiative capture are possible below 1 MeV in the cases of Ni-58 and Ni-60. Thus, the evaluations for these isotopes have been completed. Note that for the purpose of the calculation of the transfer matrices also the lumped quantity MT=10 (total continuum particle emission cross-section) has been introduced (equal to the difference between MT5 and MT102). Only for MT=10 data are given in file MF6, cf. Sect. 7.

For the other stable isotopes the JENDL-2 cross-sections are adopted. The region around E_H still needs to be inspected.

4. MF4 (angular distributions)

For the low-abundant Ni-isotopes the JENDL-2 data are used without modifications.

In the evaluation of Uhl for Ni-58 and -60 the file MF4 contained only angular distribution data for elastic scattering above 1 MeV. The angular distributions for the discrete inelastic scattring and (n.p) and (n,α) have been reconstructed from MF6 and placed in MF4, by means of a utility code written at ECN. The results still need to be checked on format errors.

For the elastic scattering angular distribution below 1 MeV the ECN evaluation was used. These data are given pointwise in KEDAK format. Since these angular distributions should be expressed in Legendre polynomials (in order to be consistent with the data file of Uhl), a conversion routine is written. This work is almost ready and no difficulties are expected.

6. MF5 (energy distributions)

Except for the minor isotopes taken from JENDL-2 there is no file MF5 given. Instead, for Ni-58 and -60 file MF6 is used (see below).

7. MF6 (energy-angle distributions)

MF6 is only used for Ni-58 and Ni-60 and only for data type MT10 (total continuum energy-angle distributions). This data type contains yields for continuum neutron, proton and alpha particle production and the corresponding energy-angle coupled distributions. The data type has been taken from the original data type MT5, introduced by M. Uhl, by multiplication of all yields with the ratio σ(MT5)/σ(MT10). A code for this transformation has been written. The application is straightforward and no difficulties are expected.

It is noted that no explicit energy-angle distributions are available for all individual reactions, like (n,2n), (n,p), etc. Strictly speaking this is not in agreement with the ENDF-VI format rules. In practice, it is probably very convenient for the user, as has been demonstrated in the case of the EFF-1 lead evaluation. The existing ECN porocessing code GROUPXS can be used to process the quantity MT10.

Finally, it may be of interest that the original file of Uhl also contained recoil spectra for all reaction products. If this information is useful these data can be stored on the JEF-2 file as well.

8. Photon-production cross sections

The JENDL-2 datafile does not contain photon production spectra for the individual isotopes, although these data are given for the natural element. The data file of Uhl contains photon production spectra for Ni-58 and Ni-60, given in file MF6. However no data are given for (n,γ) reaction below 1 MeV and no data are given for the direct-collective contribution. These data will be supplemented by ECN. The code GNASH will be used for this purpose. At high incident energies the GRAPE code system will be used to calculated the direct/semi-direct and pre-equilibrium components of the (n,γ) emission spectrum. The photon emission spectra will be stored in MF12 (multiplicities for photon production) and MF15 (energy distributions for photon production) as a lumped quantity, i.e. for the non-elastic cross-section (MT3).

For the other Ni-isotopes the multiplicities and photon production spectra for natural Ni will be used.

The total photon production spectrum for natural Ni will be compared to the experimental data.

This work will start after Jan. 1st, 1989.

9. Covariance data

No covariance data are available for the evaluation of Uhl. Some practical solution has to be found to provide these data. A difficulty is the fact that wheras the user is only interested in the uncertainties of cross-sections for the natural element, the evaluations are given only for the isotopes.

Some procedure for the creation of covariance data has to be found before the actual work can be initiated.

10. Cross-sections for the long-lived isotope Ni-59

A partial evaluation for Ni-59 is given in the KEDAK library. Furthermore, activation cross-sections are available on the REAC-ECN-3 library. It has to be decided whether a full evaluation (i.e. with scattering matrices) is necessary.

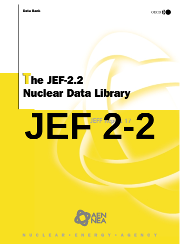


Table 1. Thermal values and resonance integrals

Table 1a: σ_γ (2200 m/s)

Isotope	Derrien + JENDL -2[a] (barn)	JEF -2[b] (barn)	BNL-325 (barn)
Ni-58	4.5701	4.563	4.6±0.3
Ni-60	2.929	2.924	2.9±0.2
Ni-61	2.464	-	2.5±0.2
Ni-62	14.417	(14.86)	14.5±0.3
Ni-64	0.7351	(1.488)	1.52±0.03

a) Calculated by the NEA Data Bank
b) Preliminary JEF-2 evaluation, except for Ni-62 and Ni-64 (JEF-1)

Table 1b: σ_{el} (2200 m/s)

Isotope	Derrien + JENDL-2[a] (barn)	JEF-2[b] (barn)	BNL-325 (barn)
Ni-58	23.938	25.817	25.3±0.4
Ni-60	0.4638	1.015	0.98±0.07
Ni-61	8.830	-	9.0±1.0
Ni-62	9.922	-	9.1±0.4
Ni-64	0.0151	-	0.0014±0.003

a) Calculated by the NEA Data Bank
b) Preliminary JEF-2 evaluation

Table 1c: I_γ

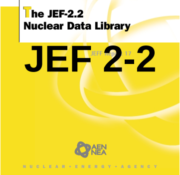
Isotope	Derrien + JENDL-2[a] (barn)	JEF-2[b] (barn)	BNL (barn)
Ni-58	2.133	2.164	2.2±0.2 (calculated)
Ni-60	1.480	1.508	1.5±0.2 (calculated)
Ni-61	1.814	-	1.5±0.4 (calculated)
Ni-62	5.882	(6.566)	6.6±0.2 (calculated)
Ni-64	0.4468	(0.789)	0.98±0.15

a) Calculated by the NEA Data Bank
b) Preliminary JEF-2 evaluation, except for Ni-62 and Ni-64 (JEF-1)

Table 2. Avarage parameters for Ni-58 and Ni-60

A	Reference	$S_0 \times 10^4$	$S_1 \times 10^4$	D_0 (keV)	$\langle\Gamma_\gamma\rangle$ (eV) l=0	$\langle\Gamma_\gamma\rangle$ (eV) l=1
58	Derrien	2.92±0.64	0.51±0.11	13.19±1.91	1.92±0.5	0.58
	Fröhner	3.2±1.0		16.7±1.6	2.3	0.5
	BNL	2.8±0.6	0.5±0.1	13.7±2.0	2.6	-
	Adopted JEF-2	2.92±0.64	0.51±0.11	15.1	$\langle\Gamma_\gamma^s\rangle$=1.015; $\langle\Gamma_\gamma^v\rangle$=0.905	0.58
60	Derrien	2.40±0.57	0.24±0.12	12.81±3.06	0.7-1.3 [a)]	0.51
	Fröhner	2.6±0.8		15.1±1.7	1.7	0.4
	BNL	2.7±0.6	0.3±0.1	16.0±2.5	1.7	0.9
	Adopted JEF-2	2.40±0.57	0.24±0.12	15.87	$\langle\Gamma_\gamma^s\rangle$=0.65; $\langle\Gamma_\gamma^v\rangle$=0.35	0.51

a) $\langle\Gamma_\gamma\rangle$ = 1.3 eV Perey et al
= 1.0 eV when 8 very strong resonances are excluded
= 0.7 eV from 16 values considered as normal below 300 keV



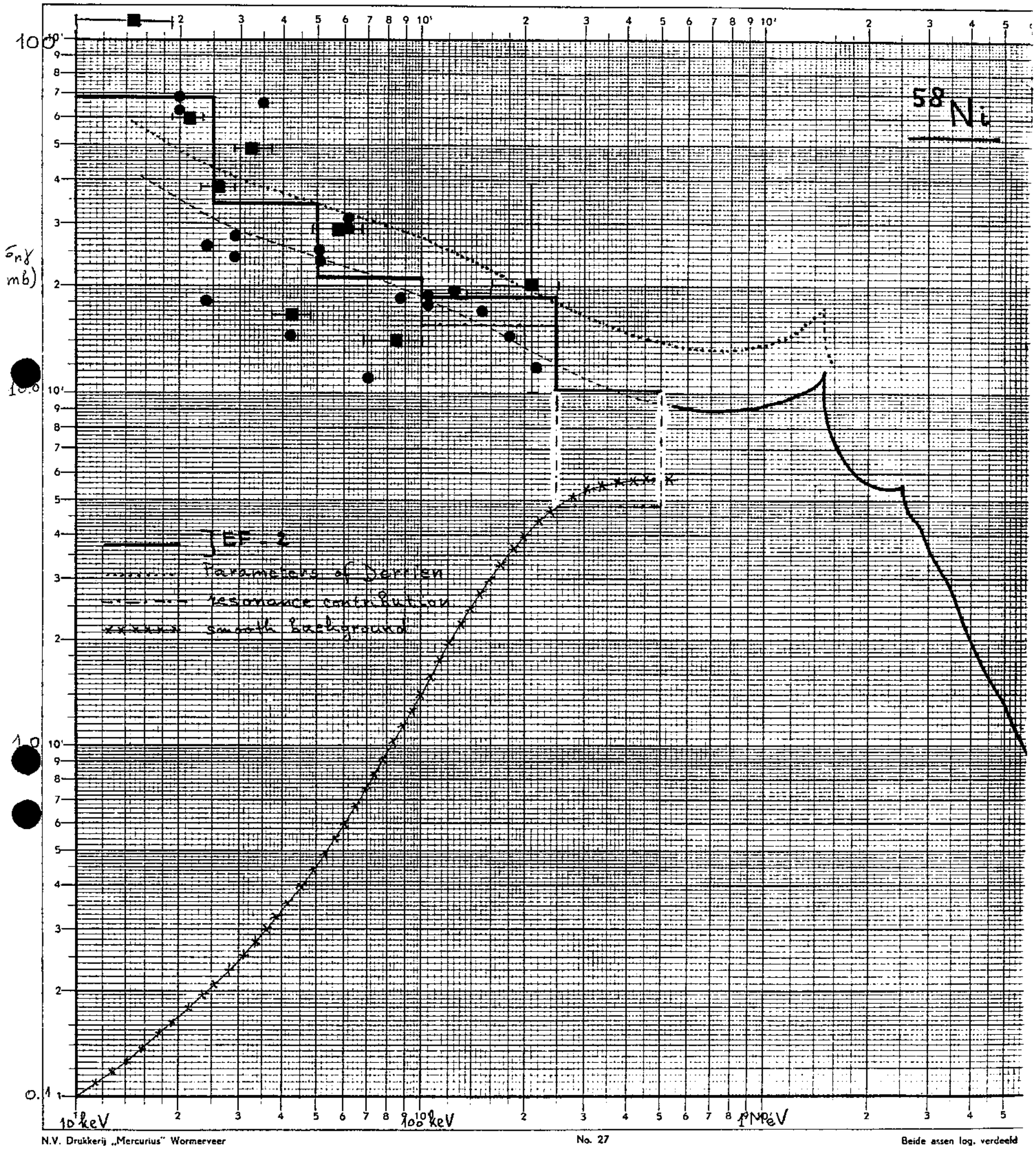


FIG. 1

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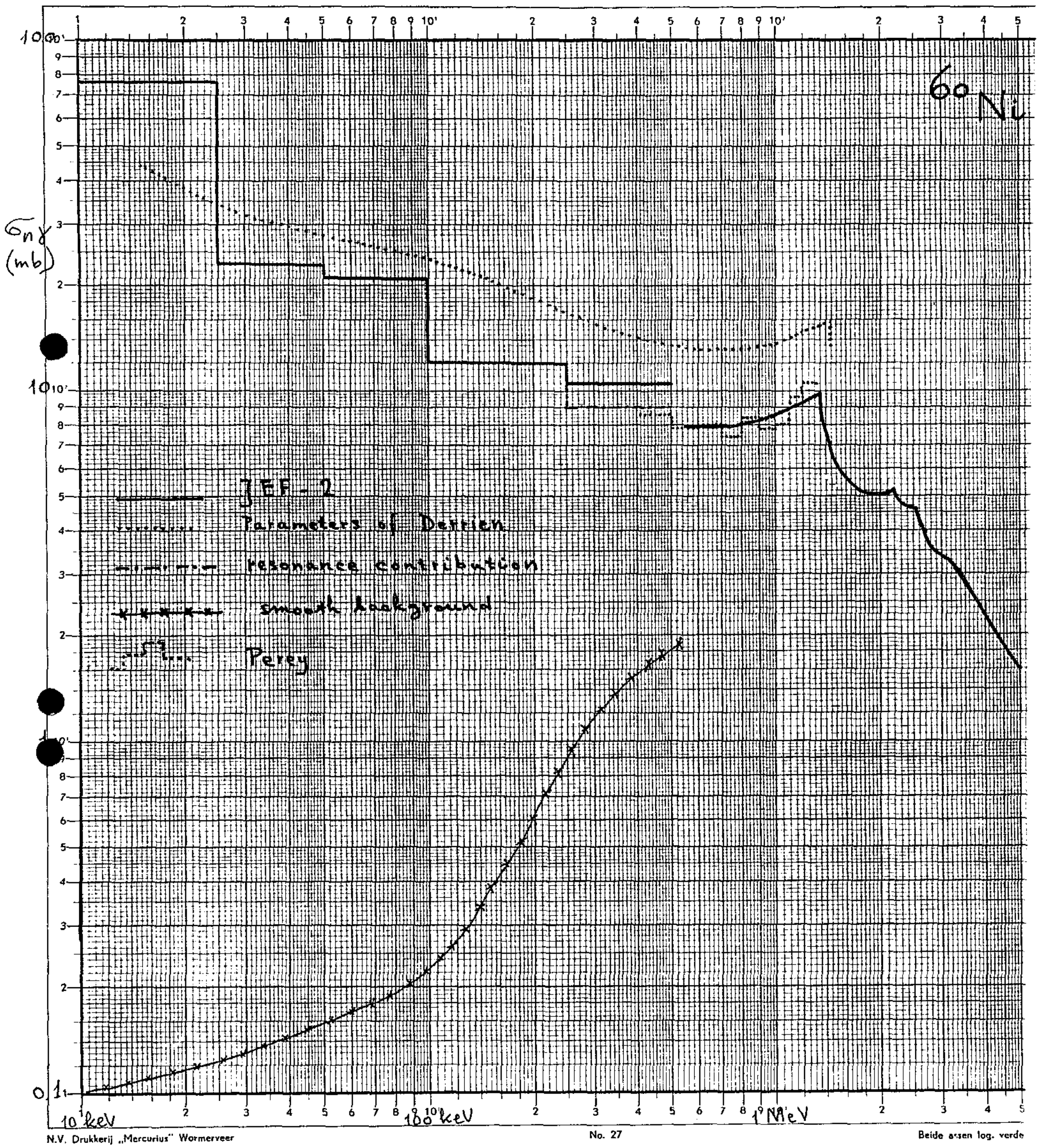
60 Ni
σnγ (mb)
JEF-2
Parameters of Derrien
resonance contribution
smooth background
Perey
10 keV
100 keV
1 MeV
N.V. Drukkerij „Mercurius" Wormerveer
No. 27
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FIG. 2

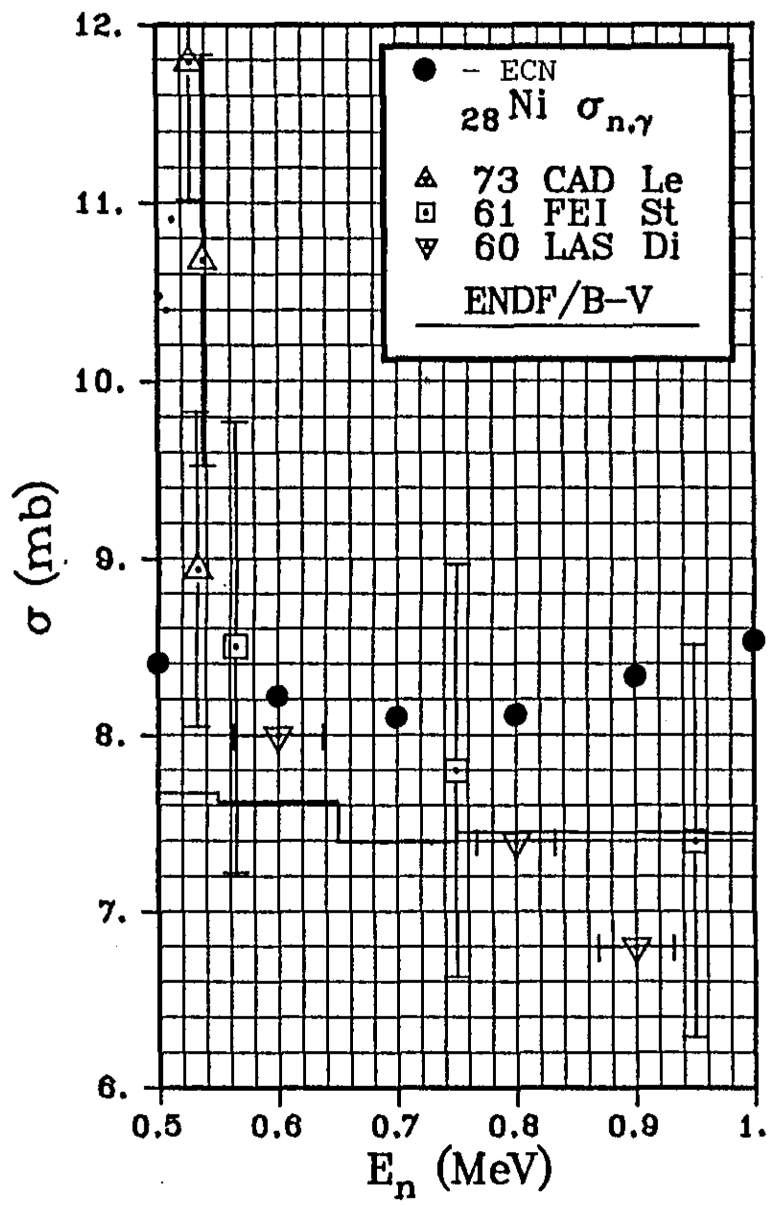

FIG. 3

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