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Status Report of Subgroup 19 to the NEANSC WPEC

May 2002

Activation cross-sections

Coordinator: A.J.M. Plompen, IRMM

The report covers the work that was carried out from March 2001 until April 2002.

Progress is listed by the laboratory leading the activity. At the end a table is given that summarizes the status of measurements of the collaboration in the context of the subgroup.

ANL D.L. Smith

- The files compiled by ANL and mentioned in the report of April 2001 have appeared in Exfor. The entry numbers are 22406 for 7 reactions on Cr isotopes that appeared in Phys. Rev. C, 22414 for the 22 reactions of the Nucl. Sci. Eng. 2000 paper, 22438 for 5 reactions on Ni and one on Cr-50 that appeared in Radiochimica Acta, and finally 22440 for two reactions on Fe-54 that appeared only in his thesis. An error occurred in entry 22438 for the reaction specifier of the Cr-50 reaction. This error was reported to Mark Kellett of the OECD Nea databank. Correction of the error in the exfor file remains to be checked. Another major error was detected recently for the ^{58}Ni(n,α)^{55}Fe reaction in entry 22438 where half of the points are missing. This remains to be reported and corrected.
- D.L. Smith compiled the data of the IRMM measurement campaigns since 2000 in Exfor format. Files have been submitted to the NEA databank for all reactions on V and Tc99. Files have been prepared for the reactions that were studied on isotopes of Pb, Mo, Ni, Cu and Co. These files remain to be checked and completed by the experimentalists at IRMM and will be submitted later this year.

IRMM/FZ-Jülich/ANL/INRNE/U.o.Debrecen, A.J.M. Plompen, P. Reimer, S.M. Qaim, D.L. Smith, V. Semkova, F. Cserpak

- The measurements for reactions on Mo isotopes were completed and presented at the ND2001 conference in Tsukuba, Japan. Similarly, results were shown for 80% of the reactions under study on Pb isotopes. The work on Pb will be finalized in the coming two months.
- Measurements on I-129, I-127, the Ag isotopes, Au and Y are ongoing. In particular, the study of I-129 is hampered by the knowledge of the sample. For Ag measurements have been carried out at FZ-Jülich that will be complemented by measurements at IRMM.
- A new effort was started for isotopes of Ni and Cu and on Co. The work serves three purposes: 1) With the help of enriched Ni-61 samples (n,xp) reactions can be studied with selectivity for the exit channel, 2) the improved study of isomer ratios (notably for ^{58}Co but also for ^{60}Co) which is partly enabled by the use of rabbit systems and a new LEGe detector, 3) the study of so far poorly studied reactions like Ni58(n,2n) and the reactions on ^{60,61,62}Ni. A feasibility study for the measurement of the Ni58(n,t)Co56 reaction is ongoing and may involve the IRMM ultra-low level underground laboratory HADES. The work up to december 2001 is summarized in EFFDOC-806 (JEFF report) and in the midterm report of V. Semkova.
- A publication covering the work on V appeared in Phys. Rev. C.

- A publication covering the work on the ^{94}Mo(n,p)^{94}Nb reaction (10^4 y half life) was accepted by Nucl. Phys. A.
- The thesis of P. Reimer was completed (U.o.Köln). It contains his work on V, Tc, Mo and Pb.
- A start was made for a new measurement project that concerns the ^{14}N(n,p)^{14}C reaction. This will start with a feasibility study that will involve AMS (U.o. Vienna) to determine the yield of ^{14}C.

NIPNE: V. Avrigeanu, M. Avrigeanu, and T. Glodariu

- Completion of the already published analysis of fast-neutron induced reactions on ^{51}V.
  (a) *Inclusion of a large data base of neutron-emission spectra* measured at PTB-Braunschweig for incident-neutron energies from 8 to 13.9 MeV proved the underestimation of the spectra at lowest energies. Thus an additional change of the neutron optical potential has been necessary, guided by the reproduction of the recent experimental neutron total cross sections for ^{51}V (IRMM, 1997). Good agreement between the experimental and calculated pre-equilibrium (PE) and statistical emission has been obtained. The high-energy end of the spectra can also be well described provided that the DWBA direct-interaction cross sections will be added.
  (b) Additional analysis of the *sensitivity of the calculated activation cross sections* in front of the, e.g., nuclear-level density parameters, has proved the high effects of the uncertainties of the experimental data considered for determination of these parameters.
  (c) The *complete calculation of the* ^{51}V*(n,d)*^{50}Ti *reaction excitation function* was based on extrapolation of the Milano-group method for α-particle PE. A deuteron pre-formation probability twice of that for α-particles has been found to describe the experimental deuteron-emission spectrum at 14.8 MeV.
  Finally, consistent model-calculations concerned again the reactions ^{51}V*(n,p)*^{51}Ti, ^{51}V*(n,α)*^{48}Sc, ^{51}V*(n,2n)*^{50}V, ^{51}V*(n,n'α)*^{47}Sc, and ^{50}V*(n,α)*^{47}Sc, and *p*-, α-particle and *d*-emission spectra produced by 15MeV neutrons, while the related parameters and calculated cross sections are given in EBDF-6 format.
  (d) All curves obtained in the evaluation were submitted to R. Forrest for the EAF file and are otherwise available in ENDF format.

- Analysis of fast-neutron induced reaction analysis for Mo isotopes.
  (a) Following recommendations of the *Workshop on Activation Data – EAF-2001* (6-7 Nov. 2000, CEA de Cadarache) for development of EAF-2003, the same consistent model calculations have been carried out also for the Mo isotopes. In order to obtain confidence in calculated cross sections, the parameter analysis carried out already (IRMM, 2000) had to be enlarged concerning the following quantities.
    (i) The analysis of the *nuclear-level density* parameters *a* and Δ of the back-shifted Fermi gas (BSFG) model carried out previously for 70 isotopes in the atomic-mass range A=79-111 by fit of the most recent experimental low-lying discrete levels and the *s*-wave nucleon resonance spacings (D_0), for the value 0.75 for the ratio between the nuclear moment of inertia I and the rigid-body value I_r of this quantity, has been extended for the I/I_r values of 0.5 and 1.0.
    (ii) The *optical model potential* (OMP) for calculation of proton transmission coefficients on the residual isotopes of Nb, for energies up to 20 MeV, has been established through the analysis of the available ^{93}Nb*(p,n)*^{93}Mo reaction

cross sections up to E_p=5.5 MeV, and total proton reaction cross sections around E_p=10 MeV. Its use has provided next good agreement with experimental cross sections of the reaction ^{93}Nb$(p,\gamma)^{94}$Mo which where published in the meantime.

(iii) A systematics of the correction factor of the γ-ray strength functions used for the *γ-ray transmission coefficients* calculation in the framework of a modified energy-dependent Breit-Wigner (EDBW) model has been established by analyzing the RIPL average radiative widths of the s-wave neutron resonance. Their correctness has been next proved by comparison of the calculated and experimental cross sections of the reactions ^{93}Nb$(n,\gamma)^{94}$Nb, and ^{92,94,95,96,97,98,100}Mo$(n,\gamma)^{93,95,96,97,98,99,101}$Mo up to E_n=2-3 MeV.

(b) The *comparison of the calculated and available experimental excitation functions* has shown a good agreement in the limit of experimental errors for the reactions:

- ^{92}Mo$(n,p)^{92}$Nb^m, ^{92}Mo$(n,\alpha)^{89}$Zr^{g,m}, ^{92}Mo$(n,2n)^{91}$Mo^{g,m}, and ^{92}Mo$(n,n'p+d)^{91}$Nb^m (including the analysis of the *proton-, α-particle, and deuteron-emission spectra* induced by 15 MeV neutrons);
- ^{94}Mo$(n,p)^{94}$Nb^{g,m}, ^{nat}Mo$(n,x)^{94}$Nb, ^{94}Mo$(n,2n)^{93}$Mo, and ^{94}Mo$(n,n'p+d)^{93}$Nb^{g,m};
- ^{95}Mo$(n,p)^{95}$Nb^{g,m} and ^{95}Mo$(n,n'p+d)^{94}$Nb;
- ^{96}Mo$(n,p)^{96}$Nb and ^{96}Mo$(n,n'p+d)^{95}$Nb^{g,m};
- ^{97}Mo$(n,p)^{97}$Nb^{g,m} and ^{97}Mo$(n,n'p+d)^{96}$Nb;
- ^{98}Mo$(n,p)^{98}$Nb^m, ^{98}Mo$(n,\alpha)^{95}$Zr, and ^{98}Mo$(n,n'p+d)^{97}$Nb^{g,m};
- ^{100}Mo$(n,\alpha)^{87}$Zr, ^{100}Mo$(n,2n)^{99}$Mo, and ^{100}Mo$(n,n'p+d)^{99}$Nb^m.

Their comparison with the new measurements of activation cross sections of Mo isotopes performed at IRMM-Geel for neutron energies from 16 to 20.5 MeV, at the same time with these calculations, could be considered a **blind exercise** and thus proves the accuracy of the approach.

- Analysis of model parameters for study of fast-neutron induced reactions on Ni isotopes.In order to validate the appropriate values of I it is carried on the analysis of the large body of experimental data for fast-neutron activation reactions on Ni isotopes, including the latest measurements just performed at IRMM-Geel., 2000). The model parameter analysis concerned the following quantities.

(i) The above-mentioned analysis of the *nuclear-level density* parameters a and Δ of the BSFG model has been carried out for 37 isotopes in the range A=59-82, for the value I/I_r=0.75.

(ii) The analysis of the neutron OMP has taken into account the recent neutron total cross section measurements performed on Ni isotopes at IRMM-Geel (1994,1995) and LANL (2001), and the SPRT method was involved for the more recent OMP parameter sets. It was thus validated the OMP of Kawano *et al.* (1991) for the isotopes ^{58,60,62,64}Ni, while modified parameter sets were derived for ^{59}Co and ^{61}Ni.

(iii*)* The OMP for calculation of proton transmission coefficients on the residual nucleus ^{58}Co has been established through the analysis of the available ^{59}Co$(p,\gamma)^{60}$Ni and ^{59}Co$(p,n)^{59}$Ni reaction cross sections up to E_p=6 MeV, and total proton reaction cross sections at E_p=10-20 MeV.

(iv) The systematics of the correction factors of the EDBW *γ-ray strength functions* was extended in the range A=41-82. Their correctness has been next proved by comparison of calculated and experimental cross sections of the reactions ^{58}Ni$(n,\gamma)^{59}$Ni, ^{60}Ni$(n,\gamma)^{61}$Ni, and ^{59}Co$(n,\gamma)^{60}$Co up to E_n=2-3 MeV.

- Systematics of the BSFG model level-density parameters for A=20–254.

Provided that it is appropriate the assumption of the value I/I_r=0.75 at B_n, the analysis of the *nuclear-level density* parameters a and Δ of the BSFG model was carried out for 343 isotopes in the range A=20-254 by the fit of the most recent experimental low-lying discrete levels (ENSDF file on BNL-Brookhaven web site) and D_0 values (the corresponding RIPL file on IAEA-Vienna web site).

- Double-folding method calculation of nuclear potential for complex particles.
  (a) *Microscopic real optical potential*, calculated in the double-folding model by using a realistic effective nucleon-nucleon (NN) interaction DDM3Y-Paris and update structure models for the α-particle, has been proved able to describe well the experimental differential elastic scattering cross sections of α-particle on ^{90}Zr and ^{100}Mo over a large energy range, from 20 MeV to 142 MeV. It predicts also elastic scattering, reaction and total cross sections in close agreement with those of the phenomenological optical potentials on the same large range of incident energies, from 20 to 142 MeV. It is thus validated the use of the microscopic potentials in the nuclear data evaluation. A systematics of the phenomenological imaginary potentials which should be consistent with the microscopic real component in this respect has been analyzed too.
  (b) *Multistep direct (MSD) calculations* were done by using single-Yukawa (1Y) equivalent NN interaction strength V_0^{eq} obtained from the DDM3Y-Paris effective interaction. They have been found to describe without any free parameter the experimental double-differential cross sections, the nucleon emission spectra from the *(p,n)* and *(p,p')* reactions on ^{90}Zr and ^{100}Mo isotopes at the incident energies of 80 MeV, 100 MeV, and 120 MeV. Thus it has also been possible to make predictions for the MSD double-differential cross sections and nucleon emission spectra corresponding to *(n,n')* and *(n,p)* reactions on ^{90}Zr and ^{100}Mo isotopes at the incident energies of 80 MeV, 100 MeV, and 120 MeV.
  (c) Since the IFMIF project requests *nuclear-data evaluation for D incident on ^{6,7}Li* for D-energies up to 50 MeV, it has been analyzed and proved the possibility to use the DF method for calculation of the nuclear potential for complex particles (e.g. ^{2,3}H, ^{3,4}He) emitted in neutron induced reactions on medium nuclei. It could be equally used for evaluation of nuclear data for D on ^{6,7}Li.

University of Debrecen: S. Sudar, J. Csikai, R. Doczi, F. Cserpak

- The model calculations for ^{99}Tc(n,p)^{99}Mo, ^{99}Tc(n,α)^{96}Nb and ^{99}Tc(n,n')^{99m}Tc have been finalized.
- New model calculations have been performed for the Pb isotopes using Stapre with Excition pre-equilibrium contributions. Their final comparison with the data was awaits the finalization of the measurement results. A publication will be prepared later this year together with the measurement results.
- A measurement campaign was started at 14 MeV to tackle selected reactions that were previously studied by Fessler et al. Focus is on reactions with short half-lives and relatively poor database at this energy.

Tohoku University: M. Baba

Measurements of neutron induced activation cross sections are in progress in the energy region from 30 to 65 or higher at the Tohoku University Cyclotron and Radioisotope Center (CYRIC) using quasi mono-energetic neutrons produced by the ^{7}Li(p,n) reaction with a few MeV thick metal target. The proton beam passing through

the target is bent with a dipole magnet into a Faraday cup which is shielded from the sample and a neutron monitor detector. Measurements use an energy degrader of carbon in front of the lithium target to change the neutron energy by several MeV without changing cyclotron tuning.
Activation samples are placed around 3 meter from the lithium target after an iron collimator. The gamma-ray spectrum is analysed with a high purity Ge gamma-ray detector. Neutron flux is measured by a TOF method using an NE213 detector. The background activity due to the non-monoenergetic component in the neutron source is eliminated with the help of theoretical model calculations and the present experiments.
Now experiments are in progress for carbon, aluminium and copper at 30, 40, 45, and 65 MeV (see the attached list). Measurements will be extended to other, in particular, higher energies and other targes. The results for $^{12}C(n,2n)^{11}C$ show large differences with past measurements.

Measurements were also done to determine ^{7}Be production in the interaction of 25 MeV deuterons with a thick Li target to assess ^{7}Be accumulation in the IFMIF target. Results showed large differences with predictions by the AIRAC code system.

First results for the neutron induced reactions were presented at the ISORD 1 conference (I-st International Symposium on Radiation Safety and Detection, July 2001, Seoul, Korea), and the results of the Li(d,x) ^{7}Be reaction were presented at the International conference on Fusion Reactor Materials (Oct. 2001, Germany) and is in print.

JAERI: K. Shibata
Cross sectons were calculated for the Na-23(n,2n) reaction up to 20 MeV using the TNG code. The results are part of JENDL-3.3. Considerable man hours were involved in the preparation and finalization of the ND2001 conference so that no further contributions could be reported.

BNL and NRG: P. Oblozinsky and A. Koning
Model calculations have been performed for the neutron-induced inelastic and charged particle reactions measured for ^{99}Tc at IRMM and FZJ. P. Oblozinsky used Empire II with TUL MSD contributions whereas A. Koning used Thalys with the two-component exciton model and a set of newly developed neutron and proton OMPs. Results will be published shortly together with the experimental data and the calculations by S. Sudar (above).

References

1. "Reaction mechanisms of fast neutrons on ^{51}V below 21 MeV", P. Reimer, V. Avrigeanu, A.J.M. Plompen, S.M. Qaim, *Phys. Rev. C65, 014604*
2. "Measurement of the $^{nat}Mo(n,x)^{94}Nb$ cross section using ultra-low level γ-ray spectrometry at HADES", P. Reimer, M. Hult, A.J.M. Plompen, P.N. Johnston, V. Avrigeanu, S.M. Qaim, *Nucl. Phys. A, in print*
3. "Recent neutron activation cross section measurements", A.J.M. Plompen, D.L. Smith, P. Reimer, S.M. Qaim, V. Semkova, F. Cserpák, V. Avrigeanu, S. Sudár, *Proc.Int.Conf. ND2001, Tsukuba, Oct 2001, in print*
4. "Vanadium cross section measurements by the activation technique and evaluations from threshold to 21 MeV", A.J.M. Plompen, P. Reimer, V. Avrigeanu, S.M. Qaim, *Proc.Int.Conf. ND2001, Tsukuba, Oct 2001, in print*

5. “Neutron induced reaction cross sections for the radioactive target nucleus ^{99}Tc”, P. Reimer, S. Sudár, P. Oblozinsky, A. Koning, S.M. Qaim, A.J.M. Plompen, *in preparation*
6. “Preequilibrium-emission surface effects in activation reactions”, M. Avrigeanu, V. Avrigeanu, A.J.M. Plompen, *Proc.Int.Conf. ND2001, Tsukuba, Oct 2001, in print*
7. “On consistent description of nuclear level density”, V. Avrigeanu, T. Glodariu, A.J.M. Plompen, H. Weigmann, *Proc.Int.Conf. ND2001, Tsukuba, Oct 2001, in print*
8. “Fast neutron induced reactions leading to activation products: selected cases relevant to development of low activation materials, transmutation and hazard assessment of nuclear waste”, P. Reimer, *thesis, jan 2002, U.o.Köln, unpublished*
9. “Recent cross section studies with the activation technique for Ni”, V. Semkova, A.J.M. Plompen, *EFFDOC-806, dec 2001, unpublished, see also EFFDOC-823, apr 2002, unpublished*
10. “Microscopic optical potential for alpha-particles interacting with ^{90}Zr”, M. Avrigeanu, A.J.M. Plompen, *report to the Intermediate Energy subgroup, JEFF mtg, apr 2002, unpublished*
11. “Measurements of Activation Cross Sections for ten’s of MeV Neutrons”, M. Hagiwara, M. Baba, H. Yashima,T.Aoki, T.Miura, N.Kawata and A.Yanadera, *Proc. I-st International Symposium on Radiation Safety and Detection, July 2001, Seoul, Korea, p.263 (The Innovative Technology Center for Radiation Safety, Hanyang University, Korea)*
12. “Experimental Studies on the Neutron Emission spectrum and Induced Activity of the ^{7}Li(d,n) reaction in the 20-40 MeV region”, M. Baba, T. Aoki, M.Hagiwara, M.Sugimoto, T.Miura, N.Kawata, A.Yamadera, H.Orihara, *Proc. 10th International Conference on Fusion Reactor Materials (Oct. 2001, Germany), Fusion Engineering & Design, to be published*

Table 1 Summary of neutron-induced reaction cross sections under study by the subgroup and the status

Nr	Lab code	Reaction	NE[1]	Energies (MeV)	Status
1	GEL	$^{nat}V(n,x)^{47}Sc$	9	11.7, 13.4, 13.9, 14.3, 15.0, 16.2, 18.0, 19.3, 20.5	sx[2],p[3]
2		$^{51}V(n,\alpha)^{48}Sc$	9	11.7, 13.4, 13.9, 14.3, 15.0, 16.2, 18.0, 19.3, 20.5	sx,p
3		$^{51}V(n,p)^{51}Ti$	2	15.0, 16.1	sx,p
4		$^{59}Co(n,2n)^{58m+g}Co$	15	13.32, 14.8, 15.27, 15.57, 15.67,16.27, 17.03, 17.19, 17.98, 18.03, 18.36, 19.29, 19.45, 19.94, 20.6	c[4], xi[5]
5		$^{58}Ni(n,p)^{58m+g}Co$	10	2.43, 14.8, 15.27, 15.67, 16.21, 17.03, 17.19, 18.82, 19.26, 20.34	c,xi
6		$^{58}Ni(n,p)$	9	0.7, 0.975, 1.4, 2.43, 3.43, 15.27, 16.08, 17.03, 19.28	w[6]
7		$^{58}Ni(n,2n)^{57}Ni$	9	14.8, 15.27,15.8, 16.14, 17.19, 17.72, 18.04, 18.82, 20.33	w
8		$^{58}Ni(n,x)^{57}Co$	13	14.8, 15.27, 15.68, 16.08, 16.27, 17.19, 17.03, 17.58, 18.04, 18.36, 18.82, 19.29, 20.33	c
9		$^{60}Ni(n,p)^{60m+g}Co$	9	13.32, 14.8, 15.27, 16.08, 17.03, 17.19, 17.97, 19.29, 19.94	c
10		$^{60}Ni(n,p)^{60m}Co$	7	14.8, 16.14, 17.03, 17.91, 19.1, 19.29, 20.35	c
11		$^{61}Ni(n,p)^{61}Co$	3	16.15, 17.95, 19.39	w
12		$^{61}Ni(n,x)^{60m}Co$	3	16.15, 17.95, 19.39	w
13		$^{62}Ni(n,x)^{61}Co$	3	16.15, 17.95, 19.39	w
14		$^{62}Ni(n,p)^{62g}Co$	3	16.14, 18.04, 20.56	w
15		$^{62}Ni(n,p)^{62m}Co$	3	16.14, 18.04, 20.56	w
16		$^{63}Cu(n,a)^{60m+g}Co$	9	13.32, 14.8, 15.99, 16.34, 17.19, 17.58, 18.18, 19.07, 19.94	c,xi
17		$^{89}Y(n,n')^{89m}Y$	10	0.84,1.4,1.96,2.46,2.95,3.4, 16.3, 18.1, 19.5, 20.7	w
18		$^{nat}Mo(n,x)^{94}Nb$	3	14.5, 18.0, 20.3	xi,ip[7]
19		$^{92}Mo(n,p)^{92m}Nb$	4	16.2, 18.0, 19.3, 20.5	xi, ip
20		$^{98}Mo(n,p)^{98m}Nb$	4	16.2, 18.0, 19.3, 20.5	xi, ip
21		$^{95}Mo(n,p)^{95m}Nb$	4	16.6, 18.0, 19.3, 20.5	xi, ip
22		$^{96}Mo(n,x)^{95m}Nb$	3	16.2, 19.3, 20.6	xi, ip
23		$^{96}Mo(n,p)^{96}Nb$	3	16.2, 19.3, 20.6	xi, ip
24		$^{97}Mo(n,x)^{96}Nb$	3	16.2, 19.3, 20.6	xi, ip
25		$^{97}Mo(n,p)^{97m}Nb$	4	16.2, 17.8, 19.2, 20.5	xi, ip
26		$^{98}Mo(n,x)^{97m}Nb$	4	16.2, 17.8, 19.2, 20.6	xi, ip

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[1] Number of energies studied

[2] sx, Submitted in Exfor Format to NEA databank

[3] published

[4] completed

[5] xi, Exfor file in preparation by the subgroup

[6] work in progress

[7] in print

[8] publised in part

27		^{98}Mo(n,x)$^{97m+g}$Nb	2	16.2, 18.0	xi, ip
28		^{92}Mo(n,α)^{89m}Zr	4	16.1, 17.8, 19.1, 20.5	xi, ip
29		^{100}Mo(n,α)^{97}Zr	4	16.2, 18.0, 19.3, 20.5	xi, ip
30		^{92}Mo(n,2n)^{91m}Mo	4	16.1, 17.8, 19.1, 20.5	xi, ip
31		^{94}Mo(n,2n)^{93m}Mo	4	16.2, 18.0, 19.3, 20.5	xi, ip
32		^{100}Mo(n,2n)^{99}Mo	4	16.2, 18.0, 19.3, 20.5	xi, ip
33		^{99}Tc(n,n'γ)^{99m}Tc	20	0.48, 0.98, 2.02, 2.98, 3.97, 4.93, 5.43, 5.91, 7.47, 8.62, 9.56,10.7, 12.4, 13.9, 14.4, 14.8, 16.3, 18.0, 19.3, 20.6	sx
34		^{99}Tc(n,p)^{99}Mo	12	8.62, 9.75,10.6, 11.6, 12.4, 13.9, 14.4, 14.8, 16.2, 17.8, 19.1, 20.4	sx
35		^{99}Tc(n,α)^{99}Mo	12	8.62, 9.75,10.6, 11.6, 12.4, 13.9, 14.4, 14.8, 16.2, 17.8, 19.1, 20.4	sx
36		^{107}Ag(n,n')^{107m}Ag	10	0.84,1.4,1.96,2.46,2.95,3.4, 16.3, 18.1, 19.5, 20.7	w
37		^{109}Ag(n,n')^{109m}Ag	10	0.84,1.4,1.96,2.46,2.95,3.4, 16.3, 18.1, 19.5, 20.7	w
38		^{197}Au(n,n')^{197m}Au	10	0.84,1.4,1.96,2.46,2.95,3.4, 16.3, 18.1, 19.5, 20.7	w
39		^{107}Ag(n,p)^{107m}Pd	4	16.3, 18.1, 19.5, 20.7	w, pp[8]
40		^{109}Ag(n,p)^{109m}Pd	4	16.3, 18.1, 19.5, 20.7	w ,pp[8]
41		^{109}Ag(n,p)^{109}Pd	4	16.3, 18.1, 19.5, 20.7	w pp[8]
42		^{107}Ag(n,α)^{104m}Rh	4	16.3, 18.1, 19.5, 20.7	w
43		^{107}Ag(n,α)^{104}Rh	4	16.3, 18.1, 19.5, 20.7	w
44		^{109}Ag(n, α)^{106m}Rh	4	16.3, 18.1, 19.5, 20.7	w
45		^{129}I(n,2n)^{128}I	4	16.3, 18.1, 19.5, 20.7	w
46		^{127}I(n,2n)^{126}I	4	16.3, 18.1, 19.5, 20.7	w
47		^{129}I(n,p)^{129}Te	4	16.3, 18.1, 19.5, 20.7	w
48		^{129}I(n,p)^{129m}Te	4	16.3, 18.1, 19.5, 20.7	w
49		^{129}I(n,α)^{126}Sb	4	16.3, 18.1, 19.5, 20.7	w
50		^{129}I(n,α)^{126m}Sb	4	16.3, 18.1, 19.5, 20.7	w
51		^{183}W(n,n')^{183m}W	6	0.84,1.4,1.96,2.46,2.95,3.4,	w
52		^{191}Ir(n,n')^{191m}Ir	10	0.84,1.4,1.96,2.46,2.95,3.4, 16.3, 18.1, 19.5, 20.7	w
53		^{nat}Pb(n,x)^{204}Tl	4	18.0, 18.7, 20.0, 20.5	xi
54		^{206}Pb(n,α)^{203}Hg	6	16.1, 17.2, 18.7, 19.2, 20.0, 20.5	xi,ip
55		^{204}Pb(n,2n)^{203}Pb	6	18.0, 18.7, 19.2, 19.4, 20.5	xi,ip
56		^{204}Pb(n,3n)^{202m}Pb	6	18.0, 18.7, 19.2, 19.4, 20.5	xi,ip
57		^{206}Pb(n,3n)^{204m}Pb	3	18.1, 19.4, 20.7	xi,ip
58		^{204}Pb(n,n')^{204m}Pb	6	3.45, 14.8, 16.25, 18.03, 19.39, 20.63	xi,ip
59		^{204}Pb(n,2n)^{203m1}Pb	4	16.14, 17.81, 19.11, 20.32	xi,ip
60		^{208}Pb(n,p)^{208}Tl	5	14.8, 16.26, 17.95, 19.3, 20.5	xi,ip
61	KOS	^{19}F(n,p)^{19}O	1	14.8	w
62		^{26}Mg(n, α)^{23}Ne	1	14.8	w
63		^{31}P(n, α)^{28}Al	1	14.8	w
64		^{50}Ti(n,p)^{50}Sc	1	14.8	w
65		^{54}Cr(n,p)^{54}V	1	14.8	w
66		^{62}Ni(n,p)^{62}Co	1	14.8	w
67		^{208}Pb(n,p)^{208}Ti	1	14.8	w
68		^{14}N(n,p)^{14}c	1	14.8	w

69		$^{129}I(n,2n)^{128}I$	1	14.8	w
70		$^{127}I(n,2n)^{126}I$	1	14.8	w
71		$^{24}Mg(n,2n)^{23m}Mg$	4	16.3, 18.1, 19.5, 20.7	w
72	TOH	Li(d,x) ^{7}Be		25	ip
73		$^{12}C(n,2n)^{11}C$		30, 40, 45, 65	w
74		$^{27}Al(n,p)^{27}Mg$		30, 40, 45, 65	w
75		$^{27}Al(n,\alpha)^{24}Na$		30, 40, 45, 65	w
76		$^{nat}Cu(n,x)^{61}Cu$		30, 40, 45, 65	w