CONF-871186--2

CONF-871186--2

DE88 002530

DESCRIPTION OF EVALUATION FOR $^{50,52,53,54}Cr$ PERFORMED FOR ENDF/B-VI

D. C. Larson, D. M. Hetrick, and C. Y. Fu
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6356

To be published in proceedings of IAEA Specialists' Meeting on the International Nuclear Data Library for Fusion Reactor Technology, Vienna, November 16-18, 1987.

DESCRIPTION OF EVALUATIONS FOR ^{50,52,53,54}Cr PERFORMED FOR ENDF/B-VI*

D. C. Larson, D. M. Hetrick, and C. Y. Fu
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6356
U. S. A.

ABSTRACT

Isotopic evaluations for ^{50,52,53,54}Cr performed for ENDF/B-VI are briefly reviewed. The evaluations are based on analysis of experimental data and results of model calculations which reproduce the experimental data. Evaluated data are given for neutron induced reaction cross sections, angular and energy distributions, and for gamma-ray production cross sections associated with the reactions. File 6 formats are used to represent energy-angle correlated data and recoil spectra. Uncertainty files are included for the major cross sections. Detailed evaluations are given for ^{52,53}Cr, and results of calculations for reactions with large cross sections are used for evaluation of the minor isotopes.

1. INTRODUCTION

Separate evaluations have been done for each of the stable isotopes of chromium. In this report we briefly review the structure of the evaluations, describe how the evaluations were done, and note the major pieces of data considered in the evaluation process. Experimental data references were obtained primarily from CINDA, but also from the literature and reports. The data themselves were mostly obtained from the National Nuclear Data Center at Brookhaven National Laboratory and, occasionally, from the literature and reports. The TNG nuclear model code (FU80,SH86), a multistep Hauser-Feshbach code which includes precompound and compound contributions to cross sections, angular, and energy distributions in a self-consistent manner, calculates gamma-ray production, and conserves angular momentum in all steps, was the primary code used for these evaluations. Extensive model calculations were performed for each isotope with the goal of simultaneously reproducing experimental data for all reaction channels with one set of parameters. This ensures internal consistency and energy conservation within the evaluation. In the case of reactions for which sufficient data were available, a Bayesian analysis using the GLUCS code (HE80) was frequently done, using ENDF/B-V or the TNG results as the prior. In cases where insufficient data were available for a GLUCS analysis and the available data were deemed to be accurate, but in disagreement with the TNG results, a line was drawn through the data and used for the evaluation. A hand-drawn line was also used for cross sections where resonant structure was felt to be important, but resonance parameters were not included. The final evaluation is thus a combination of TNG results (used where extrapolation and interpolation was required and where data sets were badly discrepant), GLUCS results (used where

*Research sponsored by the Office of Basic Energy Sciences, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

sufficient data existed to do an analysis), and hand-drawn curves. In the case of the isotopic chromium evaluations, no reaction was deemed to have enough appropriate data for a GLUCS analysis, so the evaluations depend upon TNG results and hand-drawn curves.

In Section 2 the resonance parameters are discussed; Section 3 contains a description of the major cross sections included in the evaluation; Section 4 is devoted to angular distributions; and Section 5 to energy-angle correlated distributions. Section 6 describes the uncertainty files.

Much of this information is abstracted from Ref. HE87, a report devoted to a description of the calculations for ^{52}Cr, and Ref. SH87, a similar report for ^{53}Cr. As of this writing, the various pieces of the evaluations are being reviewed, modified if necessary, and assembled into full evaluations using the ENDF/B-VI formats, and will be submitted by May 1988 to the Cross Section Evaluation Working Group (CSEWG) for use in ENDF/B-VI.

2. RESONANCE PARAMETERS

Resonance parameters are taken from Mughabghab (MU81) for energies below about 15 keV. From 15 keV to about 900 keV, the parameters are taken from recent ORNL (AG84) and Geel (BR85) transmission data. Capture resonance parameters are taken from MU81, with average parameters used where individual parameters are not available. The resonance parameters should be processed with the Reich-Moore formalism.

3. CROSS SECTIONS

In this section the evaluation of reactions with large cross sections is presented. The total cross section above the resonance region is taken from recent ORELA transmission measurements on a natural sample. However, if the high-resolution isotopic transmission data from Geel (BR85) are available, it will be used for the evaluation. Experimental data for cross sections describing inelastic scattering to discrete levels in ^{52}Cr are available for only the first two levels at incident neutron energies >4 MeV, and no data are available at 14 MeV. Thus, results of the TNG model calculations, including direct reaction contributions, were used for the evaluation. The calculations were in good agreement with available data, and with a recent measurement of the total inelastic scattering cross section from 1 to 40 MeV (LA85). Figure 1 shows a comparison of the calculated total inelastic cross section with the experimental data. Cross sections for inelastic scattering in the minor isotopes were also taken from the TNG calculations. In all cases a continuum was used to describe inelastic scattering for excitation energies above the discrete levels.

The calculated (n,p) cross sections are in acceptable agreement with the experimental data for both ^{52,53}Cr from 6 to 8 MeV, and around 14 MeV. The calculated values of the total proton emission cross sections for ^{52}Cr are in good agreement with the data of Smith and Meadows (SM80), Grimes et al. (GR79), Colli et al. (CO62) and Barschall (BA82). Since the (n,α) reaction on both ^{52,53}Cr leads to a stable nucleus, no activation data are available, only alpha production data from measured alpha spectra. For ^{52}Cr the TNG results agree within uncertainties with the data of Paulsen et al (PA81) up to 10 MeV, but are at the lower limit of the experimental uncertainties at 14 MeV for the data of Grimes et al. (GR79), Dolja et al. (DO73), and Barschall (BA82). Since much of the energy range to 20 MeV has no data, the calculated results were again taken for the evaluation. For ^{53}Cr, there is only one data point, at 14 MeV, and the calculated result is low.

Available data for the ^{52}Cr(n,2n) reaction are in disagreement near 14 MeV. The calculated results from TNG provide a reasonable compromise near 14 MeV, and are about 15% larger than the measurement of Bormann et al. (BO68) from 13 to 20 MeV. Since no data are available for the ^{53}Cr(n,2n) cross section, the calculated results were used in the evaluation. Combining the TNG results for ^{52,53}Cr give results which are in good agreement with the (n,2n) natural sample data of Auchampaugh et al. (AU77), Frehaut et al. (FR80), and Frehaut and Mosinski (FR75).

4. ANGULAR DISTRIBUTIONS

Elastic scattering angular distributions generated from the Wilmore-Hodgson potential (WI64) (used for all calculations for chromium) are in good agreement with the measured data and are given as Legendre coefficients in File 4/2. All other angular distribution information is given in File 6.

5. ENERGY-ANGLE CORRELATED DISTRIBUTIONS

Particle emission spectra are often measured as a function of outgoing particle angle, and this correlation of outgoing angle with measured energy spectra can now be represented in File 6. However, often these distributions are measured only at one incident energy, and we must rely upon model calculations to reproduce the available energy and angular distribution information so it can be calculated for the evaluation at other incident energies. File 6 is extensively used in this evaluation to represent energy-angle correlated data. Energy spectra for all outgoing particles, including photons, are given in this file. Angular distributions are given for the neutron emission spectra; for this evaluation angular distributions for all other particles are assumed to be isotropic. Figure 2 (HE87) shows a comparison of the calculated and measured angular distributions for three outgoing neutron energy bins, and Figure 3 (HE87) shows a comparison of the measured and calculated neutron emission spectra around 14 MeV incident neutron energy. These energy-angle distributions were calculated with TNG and entered in File 6 for ^{52,53}Cr at several incident neutron energies between 1 and 20 MeV.

Figures 4 and 5 (HE87) show a comparison of the measured and calculated emission spectra for the ^{52}Cr(n,xp) and ^{52}Cr(n,xα) reactions around 14 MeV. These calculated results, at several incident energies between 1 and 20 MeV, have been adopted for the evaluation and put in File 6.

Figure 6 (HE87) shows a comparison of the calculated gamma-ray emission spectrum at 9.5 MeV with the measurement of Morgan and Newman (MO76) for the bin covering incident neutron energies from 9 to 10 MeV. Calculated results from TNG at several incident neutron energies between 1 and 20 MeV were used for the evaluation, with File 6 being used for ease in calculating energy balance.

As an example of the usage of File 6, consider the $^{52}Cr(n,n\alpha)$ reaction. In File 6/22, constant yields are given for the outgoing neutron, alpha, and ^{48}Ti residual, and an energy-dependent yield is used for the gamma rays associated with the $(n,n\alpha)$ reaction. Normalized energy distributions are given for each outgoing product, but only the outgoing neutron has a non-isotropic angular distribution. The cross section to be used for normalization is taken from File 3/22.

Capture gamma-ray cross sections and spectra are given in Files 13 and 15 respectively and are based on a combination of experimental data and calculated results.

6. UNCERTAINTY INFORMATION

Uncertainty files are given only for the cross sections in File 3, and not for the resonance parameters, energy distributions or angular distributions. Fractional and absolute components, correlated only within a given energy interval, are based on scatter in experimental data and estimates of uncertainties associated with the model calculations.

REFERENCES

AG84 H. M. Agrawal, J. B. Garg, and J. A. Harvey, *Phys. Rev. C* 30(6), 1880 (1984).

AU77 G. F. Auchampaugh, D. M. Drake, and L. R. Veeser, *Neutron Cross Section Programs in the Energy Region from 1 to 24 MeV at the LASL Van de Graaff Facilities*, BNL-NCS-50681, pp. 231-246 (May 1977).

BA82 H. H. Barschall, *Europhys. Topical Conf. on Neutron Induced Reactions, Smolenice* (June 1982); Proceedings published by Slovak Acad. Sciences as *Physics and Applications*, 10, 279 (1982).

BO68 M. Bormann, A. Behrend, I. Riehle, and O. Vogel, *Nucl. Phys.* A115, 309 (July 1968).

BR85 A. Brusegan, R. Buyl, F. Corvi, L. Mewissen, F. Poortmans, G. Rohr, R. Shelley, T. Van der Veen, I. Van Marcke, "High Resolution Neutron Capture and Total Cross Section Measurements of ^{50}Cr, ^{52}Cr, and ^{53}Cr," p. 633 in *Proc. Int. Conf. Nuclear Data for Basic and Applied Science, Vol. 1, Santa Fe, N. M., May 13-17, 1985*.

CO62 L. Colli, I. Iori, S. Micheletti, and M. Pignanelli, *Nuovo Cimento* 21, 966 (1962).

DO73 G. P. Dolja, V. P. Bozhko, V. Ja. Golovnja, A. P. Kljucharev, and A. I. Tutubalin, *Proc. Nejtronnaja Fizika* 3, 131 Kiev (1973).

FR75 J. Frehaut and G. Mosinski, 5th Int. Seminar on Interaction of Fast Neutrons with Nuclei, Gaussig, (November 1975).

FR80 J. Frehaut, A. Bertin, R. Bois, and J. Jary, *Status of (n,2n) Cross Section Measurements at Bruyeres-Li-Chatel*, BNL-NCS-51245, pp. 399-411 (May 1980).

FU80 C. Y. Fu, "A Consistent Nuclear Model for Compound and Precompound Reactions with Conservation of Angular Momentum," p. 757 in *Proc. Int. Conf. Nuclear Cross Sections for Technology, Knoxville, TN, Oct. 22-26, 1979*, NBS-594, U.S. National Bureau of Standards. Also, ORNL/TM-7042 (1980).

GR79 S. M. Grimes, R. C. Haight, K. R. Alvar, H. H. Barschall, and R. R. Borchers, *Phys. Rev. C* **19**, 2127 (June 1979).

HE75 D. Hermsdorf, A. Meister, S. Sassonoff, D. Seeliger, K. Seidel, and F. Shahin, *Zentralinstitut fur Kernforschung Rossendorf Bei Dresden*, Zfk-277 (U) (1975).

HE80 D. M. Hetrick and C. Y. Fu, *GLUCS: A Generalized Least-Squares Program for Updating Cross Section Evaluations With Correlated Data Sets*, ORNL/TM-7341, ENDF-303 (October 1980).

HE87 D. M. Hetrick, C. Y. Fu, and D. C. Larson, *Calculated Neutron-Induced Cross Sections for ^{52}Cr from 1 to 20 MeV and Comparisons with Experiments*, ORNL/TM-10417, ENDF-346 (September 1987).

LA85 D. C. Larson, "High-Resolution Structural Material $(n,x\gamma)$ Production Cross Sections for $0.2 < E_n \leq 40$ MeV," p. 71 in *Proc. Conf. on Nuclear Data for Basic and Applied Science, Santa Fe, New Mexico, Vol. 1*, 1985.

MO76 G. L. Morgan and E. Newman, *The Cr(n,xγ) Reaction Cross Section for Incident Neutron Energies Between 0.2 and 20.0 MeV*, ORNL/TM-5098, ENDF-222 (January 1976).

MU81 S. F. Mughabghab, M. Divadeenam, and N. E. Holden, *Neutron Cross Sections, Vol. 1, Neutron Resonance Parameters and Thermal Cross Sections, Part A, Z=1-60*, Academic Press (1981).

PA81 A. Paulsen, H. Liskien, F. Arnotte, and R. Widera, *Nucl. Sci. and Eng.* **78**, 377 (1981).

SA72 O. A. Salnikov, G. N. Lovchikova, G. V. Kotelnikova, A. M. Trufanov, and N. I. Fetisov, *Differential Cross Sections of Inelastic Scattering Neutrons on Nuclei Cr, Mn, Fe, Co, Ni, Cu, Y, Zr, Nb, W, Bi*, Report Jadernye Konstanty -7, 102 (March 1972).

SH86 K. Shibata and C. Y. Fu, *Recent Improvements of the TNG Statistical Model Code*, ORNL/TM-10093 (August 1986).

SH87 K. Shibata and D. M. Hetrick, *Calculated Neutron-Induced Cross Sections for ^{53}Cr from 1 to 20 MeV*, ORNL/TM-10381 (1987).

SM80 D. L. Smith and J. W. Meadows, *Nucl. Sci. and Eng.* **76**, 43 (September 1980).

TA65 S. Tagesen and P. Hille, *Oesterr. Akad. Wiss., Math. Naturwiss. Kl., Sitz. Abt. 2*, **174**, 85 (March 1965).

TA83 A. Takahashi, J. Yamamoto, T. Murakami, K. Oshima, H. Oda, K. Fujimoto, M. Ueda, M. Fukazawa, Y. Yanagi, J. Miyaguchi, and K. Sumita, Oktavian Report A-83-01, Osaka University, Japan (June 1983).

VA62 D. M. Van Patter, N. Nath, S. M. Shafroth, S. S. Malik, and M. A. Rothman, *Phys. Rev.* **128**, 1246 (1962).

VO80 H. Vonach, A. Chalupka, F. Wenninger, and G. Staffel, "Measurement of the Angle-Integrated Secondary Neutron Spectra from Interaction of 14 MeV Neutrons with Medium and Heavy Nuclei," *Proc. Symp. on Neutron Cross-Sections from 10 to 50 MeV*, BNL-NCS-51245, Brookhaven National Laboratory (July 1980).

WI64 D. Wilmore and P. E. Hodgson, *Nucl. Phys.* **55**, 673 (1964).

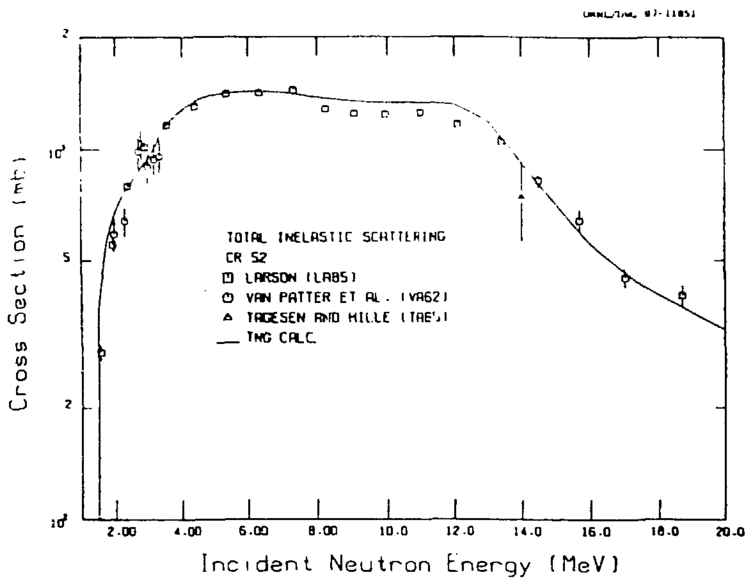

Fig. 1. Comparison of calculated and experimental total inelastic scattering cross sections for ^{52}Cr.

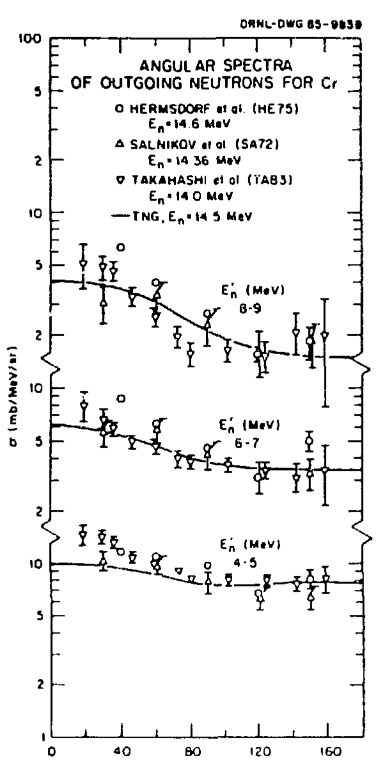

Fig. 2. Comparison of calculated and experimental neutron production cross sections.

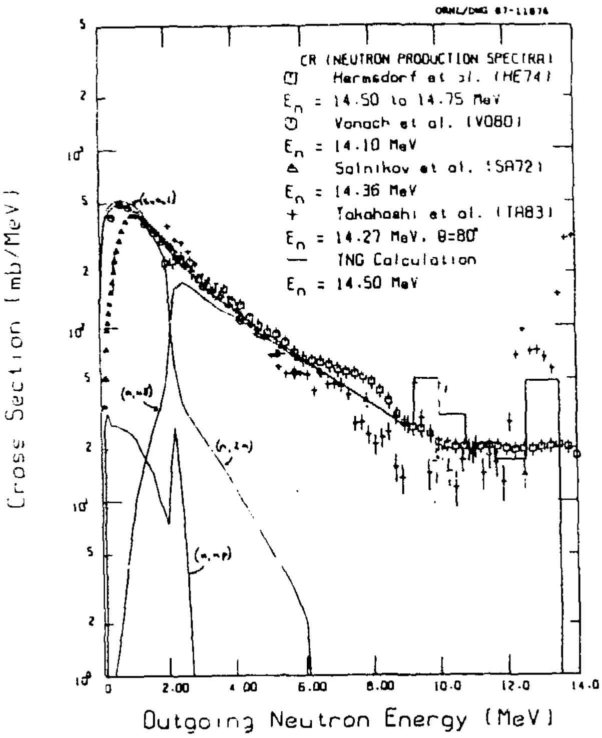

Fig. 3. **Neutron emission spectra from the TNG calculation compared with experimental data.** The data of Takahashi et al. (TA83) were taken at 80°, and the other measured data sets shown (HE74, VO80, and SA72) are angle integrated. Contributions from the various neutron-producing components are shown (they sum to the total). The curve labeled (n,np) includes the (n,pn) component. The $(n,n\alpha)$ and $(n,\alpha n)$ components were also calculated, but fall below the bottom of the plot.

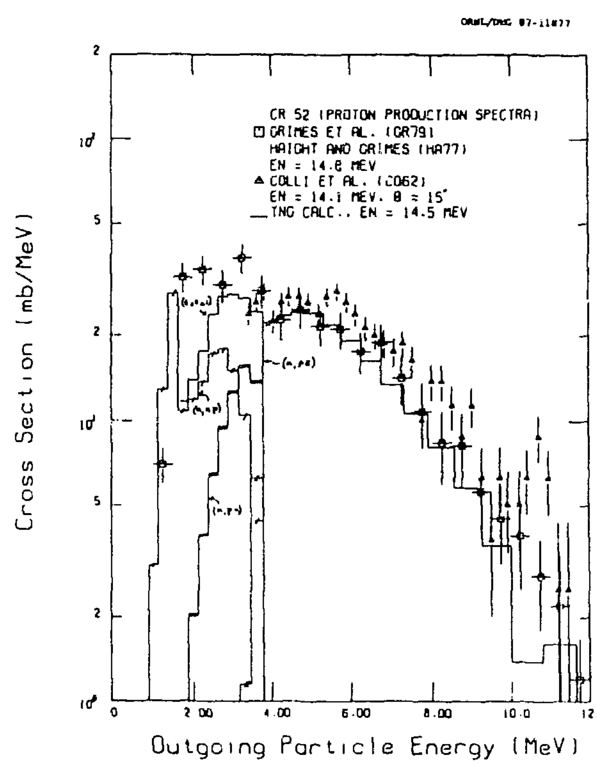

Fig. 4. **Comparison of calculated experimental proton production spectra for ^{52}Cr.** The measurements were taken at incident energies of 14.8 and 14.1 MeV; the TNG calculation was for E_n = 14.5 MeV. The data of Grimes et al. (GR79, HA77) are angle integrated; the data of Colli et al. (CO62) were taken at 15°.

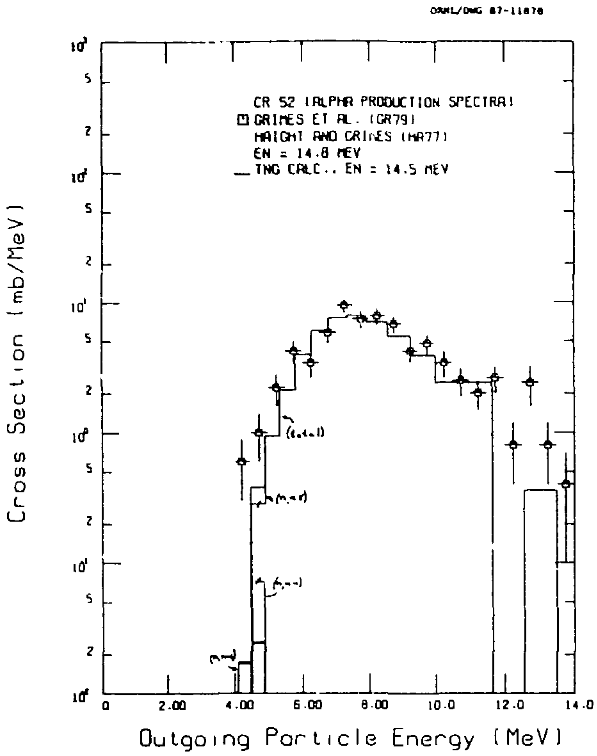

Fig. 5. Comparison of calculated and experimental alpha production spectra for ^{52}Cr. The measurement was taken at an incident energy of 14.8 MeV, the TNG calculation was for E_n = 14.5 MeV.

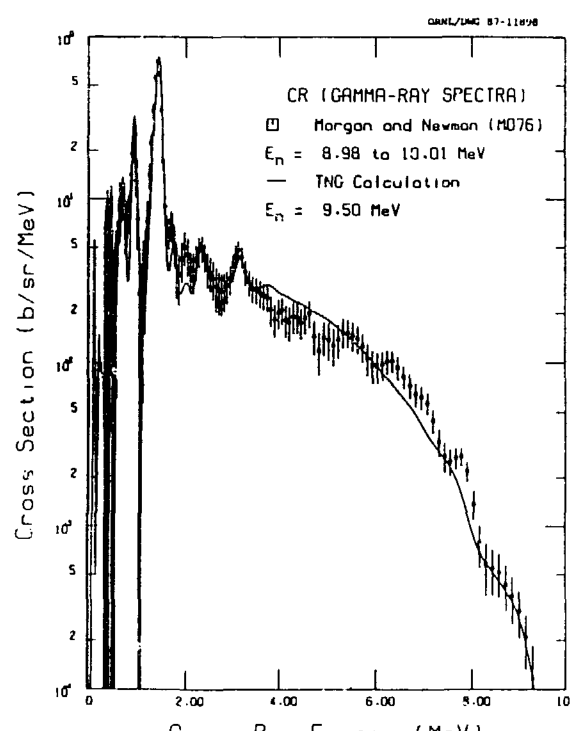

Fig. 6. Secondary gamma-ray spectra versus gamma-ray energy from the TNG calculation (incident energy E_n = 9.5 MeV) compared with the data of **Morgan and Newman (MO76).**