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Applied Nuclear Data Research and Development Quarterly Progress Report

July 1 through September 30, 1974

Edited by

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Items I, IV, V, and VI include work for DRRD. Items I, VII, and VIII include work for DMA. Items IV and V include work for DNA. Items III and VII include work for DCTR. Item II includes work for DRSR. Item IX includes work for NASA.

APPLIED NUCLEAR DATA RESEARCH AND DEVELOPMENT

QUARTERLY PROGRESS REPORT

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ABSTRACT

This report presents progress in provision of nuclear data for nuclear design applications. The work described here is carried out through the LASL Applied Nuclear Data Group and covers the period July 1 through September 30, 1974. The topical content of this report is summarized in the Contents.

I. NUCLEAR CROSS-SECTION PROCESSING (R. E. MacFarlane, R. B. Kidman, D. G. Foster, Jr., J. H. Hancock, D. R. Harris, R. J. LaBauve, D. W. Muir, W. B. Wilson, and P. D. Soran [T-1])

Group T-2 is supporting and developing a variety of computer codes for processing evaluated nuclear data into forms that can be used for design purposes. The group's capability includes multigroup neutron, gamma production, and gamma interaction cross sections; pointwise neutron and photon cross sections for continuous energy Monte Carlo codes; and a variety of data management, plotting, and format conversion functions. The following subsections summarize recent progress.

A. Cross-Section Production (R. B. Kidman, W. B. Wilson, and D. W. Muir

During this quarter, multigroup and pointwise cross sections were generated for the four tungsten isotopes ^{182}W, ^{183}W, ^{184}W, and ^{186}W from ENDF/B-IV (MATS 1128, 1129, 1130, and 1131) for the Los Alamos Scientific Laboratory (LASL) Theoretical Design (TD) Division. Multigroup cross sections in the 239 group structure[1] and CCCC-II format[2] were produced for ENDF/B-III ^{238}U and ^{239}Pu (MATS 1158 and 1159). These two isotopes and ^{16}O, ^{23}Na, and Fe (processed last quarter) were merged into a CCCC-II library using the MINX auxiliary code LINX. This library has been sent to Westinghouse Advanced Reactor Division (WARD) to test the MINX/SPHINX interface. In order to test the interface between MINX and other codes in the CCCC-III format,[3] a two-nuclide test library was generated and sent to LASL group T-1. Some problems were found in the free format BCD input and in the handling of the higher order elastic scattering matrices. The appropriate corrections have been made and a new library has been generated. The computer codes ETOX[4] and 1DX[5] were used to generate preliminary resonance self-shielded cross sections to be used in neutronics and safety calculations for a fission driven laser being studied by LASL group P-5. As the project progresses, more refined cross sections and computations will be provided. Multigroup elastic cross sections and transfer matrices for iron between 20 and 60 MeV were produced using MINX and a special data file formed with elastic scattering cross sections determined from the difference between existing total and nonelastic cross-section data. Angular distributions for elastic scattering were determined by optical model calculations with ABACUS-II[6] for which potential parameters were determined from interpolation and extrapolation from parameters of earlier optical model fits to measured angular distributions.[7] These cross sections will be used in the design of a neutron radiotherapy shield.[8]

B. MINX Code Development (R. E. MacFarlane, R. B. Kidman, and J. H. Hancock)

A number of corrections and additions to the MINX code were made during this quarter. ENDF/B-IV includes a description of the sequential (n,2n) reaction in ^{9}Be. The necessary coding was added to treat the first neutron as discrete inelastic scattering (MT 6, 7, 8, 9), the second neutron as continuum inelastic scattering (MT 46, 47, 48, 49), and to collect the results into a total (n,2n) scattering matrix. For some shielding problems it is important to have a thermal group. One of the weighting functions in MINX has been modified to include a thermal Maxwellian weight below a breakpoint, a 1/E weight from this point to a second breakpoint, and a fission spectrum above the second breakpoint. The two breakpoints and temperatures are specified by the user. The third significant modification this quarter was to convert the output of MINX to the CCCC version III interface format.[3] During this conversion several ambiguities and shortcomings of the CCCC interface were encountered. Our recommendations will be communicated to the Code Working Group of the U. S. Atomic Energy Commission Division of Reactor Research and Development (DRRD). Finally, several small additions and corrections were made including additional comments, reduction in printed output, repair of an error in the storage of Legendre coefficients, and correction of the fission chi vector calculation.

C. MINX Auxiliary Codes (R. B. Kidman, R. E. MacFarlane, D. W. Muir, P. D. Soran [T-1], and R. J. LaBauve)

The CCCC auxiliary codes for MINX have been extensively rewritten and converted to CCCC-III format. Also, a new code has been added to provide a temporary link to the 1DX code.[9] The current auxiliary codes are: BINX, convert CCCC ISOTXS and BRKOXS files from binary to BCD and back and list files if desired; LINX, merge two binary ISOTXS or BRKOXS libraries into a single new binary library; CINX, collapse ISOTXS and BRKOXS libraries to a coarser group structure (not operational); and FCFTR, combine ISOTXS and BRKOXS libraries to obtain a new library in the FTRSET-300 format[10] for use by 1DX.

MINX is also capable of producing output directly in DTF format using an output module called DTFLIB. This path is used to supply data to the LASL TD Division and the LASL controlled thermonuclear reactor (CTR) program. It also has been used for such internal programs as the Texas A & M radiotherapy shield project.[8] In the DTF mode, MINX uses an auxiliary code MINXPLOT to produce graphs of groupwise cross sections overlayed on the pointwise cross sections for each reaction. This code has been modified this quarter to improve its ease of operation. Also a thinning routine has been added to the section which plots pointwise data in order to reduce the detail plotted in resonance regions.

D. Processing Code Validation and Comparison (R. B. Kidman and R. J. LaBauve)

A multiauthored paper entitled "Fast Reactor Cross-Section Processing Codes -- Is There a Dollars Worth of Difference Between Them?" was presented at the September Atlanta meeting of the American Nuclear Society, (ANS) Advanced Reactors: Physics, Design and Economics.[11] Its purpose was to complete a first pass at discovering academic and practical differences among various cross-section processing codes. LASL's contribution to the paper included discussions and ZPR-6-7 benchmark results for both ETOX and MINX codes. In general, differences were found but their practical consequences were not established. In order to do that plus eliminate coding errors, a much more detailed and in-depth study would be required. A program to perform these studies will be discussed at the "Physics Codes Evaluation Meeting" of the Atomic Energy Commission in Washington D. C. on November 1, 1974.

E. MINX-II Development (R. E. MacFarlane, D. G. Foster, Jr., and J. H. Hancock)

MINX-II is a highly modular code designed to perform the functions of MINX (multigroup neutron interaction cross sections and n → n' transfer matrices), LAPHAN[12] (multigroup photon production cross sections and n → γ transfer matrices, GAMLEG[13] (photon interaction cross sections), ETOPL[14] (preparation of point libraries for continuous energy Monte Carlo codes), and FLANGE[15] (multigroup thermal neutron scattering cross sections and transfer matrices). In order to communicate the results to a wide variety of users, the processing modules of MINX-II generate an extremely general intermediate library. This library can then be collapsed and converted to a wide variety of output formats using simple postprocessor modules. In addition, service modules can be called upon to perform editing, listing, and plotting functions. The modules now under development are described below.

RECONR reconstructs pointwise cross sections on a unionized grid such that all the reaction cross sections can be represented by linear-linear interpolation within a specified accuracy. This form allows for efficient retrieval by Monte Carlo codes and is especially suitable for Doppler broadening and group averaging. It also makes it possible to assure that "redundant" reactions (e.g., total, total inelastic, total fission) are equal to the sum of their parts. This module reads from an ENDF/B file and writes its results onto a PENDF (Pointwise ENDF) file.

UNRESR computes self-shielded temperature-dependent pointwise cross sections in the unresolved resonance region. The method used is that of ETOX[16] modified for the MINX-II environment. The input file is ENDF/B and the output is written on a special interface file UNRXS for use by other modules.

GROUPR computes groupwise self-shielded temperature-dependent neutron interaction and gamma production cross sections, n → n' and n → γ transfer matrices, average number of fission neutrons ($\bar{\nu}$) for prompt and delayed neutrons by time group, and fission spectrum (χ) vectors for prompt and delayed neutrons by time group. The module reads from ENDF/B, PENDF, and UNRXS files and writes its results onto a special intermediate library called GENDF (Groupwise ENDF).

BROADR Doppler broadens and/or thins pointwise cross sections from a PENDF file. The broadening algorithm works for very high temperatures, and the thinning preserves the unionization of the grid without removing important features such as resonances. The result is also in PENDF format.

When these four modules are completed, MINX-II will be able to process all reactions with neutrons in and neutrons or photons out including delayed neutrons. At the current time BROADR is not operational and the transfer matrices in GROUPR are not implemented. Self-shielded gamma production cross sections can be generated successfully (including correct treatment of the resolved and unresolved energy ranges), and the delayed neutron files for ENDF/B-IV can be processed.

The UNRESR module was completed this quarter. It is very similar to the unresolved calculation from MINX. The self-shielded cross section calculation was also implemented. An attempt was made to improve the efficiency of this part of the code. In a runoff using the same PENDF tape, MINX took 37.0 s to compute the elastic cross sections at 300°K for five dilutions. MINX-II took 6.7 s for the same problem. The coding for processing secondary energy distributions (ENDF/B files 5 and 15) was completed this quarter. This allows the calculation of delayed neutron $\bar{\nu}$ and spectra by time group. MINX-II is the first code capable of processing the new delayed neutron sections in ENDF/B-IV.

Work was substantially completed this quarter on a subset of the routines for generating "feed functions" (i.e, the total scattering into sink group g' from source energy E) for group-to-group transfer cross sections for elastic and discrete inelastic scattering. The critical points for the feed function to a given sink group are the four discontinuities in slope of the feed function, corresponding to $\mu = \pm 1$ for scattering to the upper and lower boundaries of the sink group. These are calculated in a subroutine which always produces non-negative solutions and correctly deals with various exceptional cases. The feed function for angular distributions given as Legendre coefficients in the laboratory system is calculated analytically using the same algorithm as MINX. If the source group includes the critical energy (at which the secondary energy becomes double valued) it is truncated at E_c but begins with the correct limiting value in all flux orders. For Legendre coefficients given in the center-of-mass system a numerical integration is required, but the results are valid for any energy above threshold. For this integration an adaptive Simpson's-rule subroutine was written using a dynamic cosine grid to minimize storage requirements. The initial grid is estimated from the maximum order of Legendre coefficient in the data. Points are added as necessary to achieve convergence on the lowest interval, and then dropped when they have been used. No value of the integrand needs to be computed more than once, and 30 points are sufficient for the worst angular distribution tested. The feed function itself is generated on a dynamic grid in a similar fashion. The grid manager is primed with the critical points and run to convergence on the lowest interval in the feed function. Thereafter the manager supplies values of the feed function interpolated to the required precision, dropping intervals and adding new ones (again refined until convergence) as required. With minor modifications the routines in this subset can be used directly to convert Legendre coefficients from center-of-mass to laboratory coordinates and *vice versa*.

F. Processing Code Theory (R. E. MacFarlane, D. R. Harris, M. Becker [Rensselaer Polytechnic Institute])

For use in practical design problems, the MINX and SPHINX[17] codes will combine to form self-shielded geometry-dependent macroscopic cross sections. This procedure is usually described as the Bondarenko method.[18] The approximations implicit in this method have been examined with respect to the advanced capabilities of MINX and SPHINX (e.g., elastic transfer matrices, supergroup structures, anisotropic transport), and several possible trouble areas have been identified for further study. These include elastic transfer matrix self-shielding, collapse theory, transport approximations, and weighting theory. The problems with weighting theory arise for anisotropic scattering, broad resonances, and small-dilution strong-structure situations. Theoretical studies and numerical tests are underway.

II. NUCLEAR DATA PROCESSING FOR HTGR SAFETY RESEARCH (M. G. Stamatelatos and R. J. LaBauve

The multigroup cross sections for high temperature gas-cooled reactor (HTGR) neutronic calculations are generated from basic data with the use of a number of available computer programs. For this purpose a number of computer codes were made operational at LASL -- MC^2 (Ref. 19), FLANGE,[15] GLEN,[20] JMBLFAT,[21] TOR,[22] HEXSCAT,[23] and GASKET.[24] The broad-group energy structure and the nuclides used are given in Tables I and II. The various paths of data flow for broad-group cross-section generation are shown in Fig. 1.

At present, the MC^2 code is used to generate the cross sections for all absorber nuclides and for the above-thermal cross sections of the graphite moderator. Future plans call for the use of MINX-SPHINX codes when the latter becomes operational at LASL.

TABLE I

BROAD-GROUP ENERGY STRUCTURE

$E_{max} = 10.00$ MeV

Group No.	Lower Energy (Nominal) (eV)	Lower Energy (Actual) (eV)
1	1.83×10^{5}	1.8316×10^{5}
2	9.61×10^{2}	9.6112×10^{2}
3	1.76×10^{1}	1.7603×10^{1}
4	3.93	3.9279
5	2.38	2.3800
6	4.14×10^{-1}	4.1358×10^{-1}
7	1.00×10^{-1}	1.0457×10^{-1}
8	4.00×10^{-2}	3.8469×10^{-2}
9	5.00×10^{-4}	5.4873×10^{-4}

TABLE II

HTGR NUCLIDES FOR WHICH
CROSS SECTIONS WERE GENERATED

Nuclide	ENDF/B Version 3 MAT No.	Temperature (°K)
Th232	1117	296.00
U234	1043	296.00
U235	1157	296.00
U238	1158	296.00
C12	1165	296.00
O16	1134	296.00
Si	1151	296.00
U236	1163	296.00
Th232	1117	500.00
U235	1157	500.00
B10	1155	296.00
Th232	1117	800.00
U235	1157	800.00
Th232	1117	1200.00
U235	1157	1200.00

The use of MC^2 is affected by computer storage limitations when considering the energy range of interest (10 MeV to 0.0005 eV). Thus, cross sections for the above-thermal (10 MeV to 0.414 eV) and the thermal (2.38 eV to 0.0005 eV) neutron energy ranges are generated in two separate but overlapping passes. Only the "all fine" option is used in MC^2 with uniform fine-group spacings of 0.25 in lethargy for the above-thermal problems and 0.125 for the thermal problem.

For the above-thermal problem, MC^2 calculates the neutron flux and uses it as a weighting function for collapsing fine-group cross sections to broad-group data.

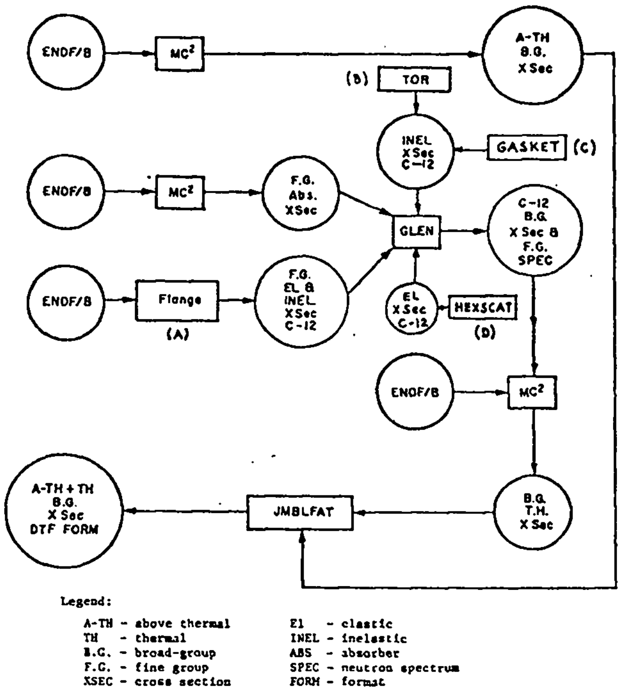

Fig. 1. Data flow for HTGR broad-group cross-section generation.

For the thermal problem, MC^2 also calculates a 1/E neutron spectrum which, however, is not the true spectrum in this energy region. Therefore, the broad-group cross sections obtained by collapsing the fine-group absorber cross sections are incorrect.

GLEN, which calculates a much better neutron spectrum, requires as input fine-group cross sections for absorbers which are provided by MC^2. It also requires fine-group elastic (MT = 2) and inelastic (MT = 4) cross sections for graphite.

The graphite cross sections have been calculated via several alternate routes for comparison. They can be taken and interpolated from ENDF/B graphite data processed by GASKET and HEXSCAT. This is done by the code FLANGE. Alternately, the coherent elastic scattering can be calculated directly by HEXSCAT and the scattering law can be calculated by two relatively equivalent codes, TOR and GASKET. The former code calculates the Fourier integrals in the scattering law "directly" while the latter uses a "phonon expansion."

The spectrum calculated by GLEN is used by MC^2 for properly collapsing the fine- (68) group cross sections to broad- (9) group cross sections for the absorbers.

Finally JMBLFAT merges the above-thermal and the thermal broad-group cross sections and ouputs them in DTF format required by the discrete ordinates S_n transport code.

Since there are several alternate ways of calculating the graphite thermal cross sections, it is interesting to compare some quantities calculated via the various routes, e.g., the scattering law, the fine-group neutron spectrum, and the broad-group cross sections. Some differences are expected at least due to the slightly different phonon distributions used in TOR and in the GASKET runs which generated the ENDF/B scattering law data.

III. NUCLEAR DATA FOR THE CONTROLLED FUSION PROGRAM
(D. W. Muir, D. R. Harris, L. Stewart, and D. M. McClellan)

In this quarter we have produced a library of processed reaction cross sections of use in CTR activation and transmutation studies. Reaction cross sections for 73 nuclides of interest in CTR nuclear design were calculated at Brookhaven National Laboratory (BNL) using the nuclear systematics code THRESH.[25] Pointwise cross sections for ten important threshold reactions were written onto a magnetic tape in ENDF/B format and distributed by BNL. Also distributed was a tape containing similar data for CTR materials already contained in the ENDF/A and ENDF/B-III files. These two tapes of pointwise data were processed by the LASL Nuclear Data Group into the GAM-II, 100-neutron-energy-group structure, using the multigroup processing code ETOG.[26] The resulting multigroup data (for 687 distinct nuclear reactions) are available on a BCD card-image tape for external distribution. The reactions available are listed in Table III along with the half-life of the product and the source of the data. Under data sources, the entry "COOK" refers to Ref. 27; "BENZI" to Ref. 28; and "UKAEA" to Ref. 29. In the last column is given a reaction identification number which combines the charge and mass of the target with an index of the reaction type.

Work has begun on a new program to determine in detail the highest priority areas for near-term nuclear data reseach and development fcr the national CTR program. This assessment will take into account the quality of currently available data, the sensitivity of important blanket parameters to data uncertainty, and the accuracy required in CTR design applications.

An appropriate tool for survey calculations of this type is first-order perturbation theory. In this approximation, the standard deviation ΔR in a design parameter R can be written as follows:[30,31]

$$(\Delta R)^2 = \sum_{i,j} \frac{\partial R}{\partial X_i} \frac{\partial R}{\partial X_j} \, \mathrm{Cov}(X_i,X_j) \quad . \qquad (1)$$

The quantities $\frac{\partial R}{\partial X_i}$, the so-called "sensitivities," can be constructed from the forward and adjoint fluxes for the particular neutron transport problem of interest.[32]

In Eq. (1) X_i is the cross section for a particular nuclear reaction at a particular neutron energy. The covariance matrix $\mathrm{Cov}(X_i,X_j)$ is related to the joint probability density $f(X_i,X_j)$ for the two cross sections X_i and X_j as follows:

$$\mathrm{Cov}(X_i,X_j) = \iint_{-\infty}^{\infty} f(X_i,X_j)(X_i-\hat{X}_i)(X_j-\hat{X}_j)\,dX_i\,dX_j \; . \qquad (2)$$

Here, $\hat{X}_i$ is the expectation value of X_i.

The diagonal terms of the covariance matrix, that is $\mathrm{Cov}(X_i,X_i)$, are the usual (uncorrelated) cross-section uncertainties, $(\Delta X_i)^2$. Information of this type has been compiled recently for a wide variety of CTR materials by the CTR Subcommittee of the U. S. Nuclear Data Committee.[33]

Off-diagonal terms of the covariance matrix also can be important in estimating the uncertainty ΔR in Eq. (1). For example, let X_i be the neutron elastic scattering cross section and X_j the nonelastic cross section in an energy region where the elastic is obtained by subtraction from the total, $\sigma_{tot}(E)$. That is,

$$X_i = \sigma_{tot}(E) - X_j \quad . \qquad (3)$$

Using Eq. (3) to make a change of variables in Eq. (2), we have immediately (X_i and X_j anticorrelated)

$$\mathrm{Cov}(X_i,X_j) = -\mathrm{Cov}(X_i,X_i) = -(\Delta X_i)^2 \quad .$$

Important correlations also exist between the cross sections for the same reaction but at different neutron energies. These can be treated in a straightforward fashion through the use of the "range parameter" formalism.[30]

This data uncertainty information also can be used[34,35] to construct alternative data sets which permit direct computations of alternative values for CTR design parameters.

TABLE III

MULTIGROUP REACTION CROSS SECTIONS FOR CTR ACTIVATION/TRANSMUTATION STUDIES

Reaction	Product Half Life	Data Source	Identification
H-1(N,G)H-2	STABLE	ENDF/B-3	1012
HE-3(N,P)H-3	12.3 Y	ENDF/B-3	2033
HE-3(N,NP+D)H-2	STABLE	ENDF/B-3	2035
HE-3(N,NP+D)H-2	STABLE	UKAEA	2035
HE-4(N,P)H-3	12.3 Y	.00013ENDF/B-3	2043
LI-6(N,G)LI-7	STABLE	ENDF/B-3	3062
LI-6(N,P)HE-6	802. MS	ENDF/B-3	3063
LI-6(N,A)H-3	12.3 Y	ENDF/B-3	3064
LI-7(N,2N)LI-6	STABLE	ENDF/B-3	3071
LI-7(N,G)LI-8	850. MS	ENDF/B-3	3072
LI-7(N,NP+D)HE-6	802. MS	ENDF/B-3	3075
BE-9(N,2N)BE-8	1. E-16S	ENDF/B-3	4091
BE-9(N,G)BE-10	2.7 E+6 Y	ENDF/B-3	4092
BE-9(N,P)LI-9	.18 S	ENDF/B-3	4093
BE-9(N,A)HE-6	802. MS	ENDF/B-3	4094
BE-9(N,NP+D)LI-8	850. MS	ENDF/B-3	4095
BE-9(N,T)LI-7	STABLE	ENDF/B-3	4097
B-10(N,P)BE-10	2.7 E+6 Y	UKAEA	5103
B-10(N,A)LI-7	STABLE	ENDF/B-3	5104
B-10(N,NP+D)BE-9	STABLE	ENDF/B-3	5105
B-10(N,T)BE-8	1. E-16 S	ENDF/B-3	5107
B-11(N,G)B-12	20.4 MS	ENDF/B-3	5112

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B-11(N,P)BE-11          14.      S        ENDF/B-3     5113
B-11(N,A)LI-8           850.    MS        ENDF/B-3     5114
B-11(N,T)BE-9           STABLE            ENDF/B-3     5117
C-12(N,G)C-13           STABLE            ENDF/B-3     6122
C-12(N,A)BE-9           STABLE            ENDF/B-3     6124
N-14(N,2N)N-13          10.      M        ENDF/B-3     7141
N-14(N,G)N-15           STABLE            ENDF/B-3     7142
N-14(N,P)C-14           5730.    Y        ENDF/B-3     7143
N-14(N,A)B-11           STABLE            ENDF/B-3     7144
N-14(N,NP+D)C-13        STABLE            ENDF/B-3     7145
N-14(N,T)C-12           STABLE            ENDF/B-3     7147
O-16(N,G)O-17           STABLE            ENDF/B-3     8162
O-16(N,P)N-16           7.1      S        ENDF/B-3     8163
O-16(N,A)C-13           STABLE            ENDF/B-3     8164
O-16(N,NP+D)N-15        STABLE            ENDF/B-3     8165
F-19(N,2N)F-18          110.     M        UKAEA        9191
F-19(N,2N)F-18          110.     M        UKAEA        9191
NA-23(N,2N)NA-22        2.6      Y        ENDF/B-3    11231
NA-23(N,G)NA-24         STABLE            ENDF/B-3    11232
NA-23(N,P)NE-23         38.      S        ENDF/B-3    11233
NA-23(N,A)F-20          11.      S        ENDF/B-3    11234
AL-27(N,2N)AL-26        7.3  E+5 Y        ENDF/B-3    13271
AL-27(N,G)AL-28         2.3      M        ENDF/B-3    13272
AL-27(N,P)MG-27         9.5      M        ENDF/B-3    13273
AL-27(N,A)NA-24         15.      H        ENDF/B-3    13274
AL-27(N,NP+D)MG-26      STABLE            ENDF/B-3    13275
AL-27(N,T)MG-25         STABLE            ENDF/B-3    13277
SI-28(N,P)AL-28         2.3      M        UKAEA       14283
P-31(N,P)SI-31          2.6      H        UKAEA       15313
K-39(N,N)K-39           STABLE     ZEROES ENDF/B-3    19390
K-39(N,2N)K-38          7.6     MGS+ISO.ENDF/B-3      19391
K-39(N,G)K-40           1.3  E+9 Y        ENDF/B-3    19392
K-39(N,P)AR-39          269.     Y        ENDF/B-3    19393
K-39(N,A)CL-36          3.7  E+5 Y        ENDF/B-3    19394
TI-46(N,2N)TI-45        3.08     H        THRESH      22461
TI-46(N,P)SC-46         *                 THRESH      22463
TI-46(N,A)CA-43         STABLE            THRESH      22464
TI-46(N,NP+D)SC-45      STABLE            THRESH      22465
TI-46(N,NA)CA-42        STABLE            THRESH      22466
TI-47(N,2N)TI-46        STABLE            THRESH      22471
TI-47(N,P)SC-47         3.35     D        THRESH      22473
TI-47(N,A)CA-44         STABLE            THRESH      22474
TI-47(N,NP+D)SC-46      *                 THRESH      22475
TI-47(N,NP+D)SC-46      *                 THRESH      22475
TI-47(N,NA)CA-43        STABLE            THRESH      22476
TI-47(N,T)SC-45         STABLE            THRESH      22477
TI-47(N,HE-3)CA-45      162.7    D        THRESH      22479
TI-48(N,2N)TI-47        STABLE            THRESH      22481
TI-48(N,P)SC-48         1.82     D        THRESH      22483
TI-48(N,A)CA-45         162.7    D        THRESH      22484
TI-48(N,NP+D)SC-47      3.4      D        THRESH      22485
TI-48(N,NP+D)SC-47      3.35     D        THRESH      22485
TI-48(N,NA)CA-44        STABLE            THRESH      22486
TI-48(N,T)SC-46         *                 THRESH      22487
TI-48(N,HE-3)CA-46      STABLE            THRESH      22489
TI-49(N,2N)TI-48        STABLE            THRESH      22491
TI-49(N,P)SC-49         57.5     M        THRESH      22493
TI-49(N,A)CA-46         STABLE            THRESH      22494
TI-49(N,NP+D)SC-48      1.8      D        THRESH      22495
TI-49(N,NP+D)SC-48      1.82     D        THRESH      22495
TI-49(N,NA)CA-45        162.7    D        THRESH      22496
TI-49(N,T)SC-47         3.35     D        THRESH      22497
TI-49(N,HE-3)CA-47      4.53     D        THRESH      22499
TI-50(N,2N)TI-49        STABLE            THRESH      22501
TI-50(N,P)SC-50         *                 THRESH      22503
TI-50(N,A)CA-47         4.53     D        THRESH      22504
TI-50(N,NP+D)SC-49      57.5     M        THRESH      22505
TI-50(N,NP+D)SC-49      57.5     M        THRESH      22505
TI-50(N,NA)CA-46        STABLE            THRESH      22506
TI-50(N,T)SC-48         1.82     D        THRESH      22507
TI-50(N,HE-3)CA-48      STABLE            THRESH      22509
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V-49(N,2N)V-48          16.1      D       THRESH     23491
V-49(N,P)TI-49          STABLE            THRESH     23493
V-49(N,A)SC-46          *                 THRESH     23494
V-49(N,NP+D)TI-48       STABLE            THRESH     23495
V-49(N,NA)SC-45         STABLE            THRESH     23496
V-50(N,2N)V-49          331.      D       THRESH     23501
V-50(N,P)TI-50          STABLE            THRESH     23503
V-50(N,A)SC-47          3.4       D       THRESH     23504
V-50(N,NP+D)TI-49       STABLE            THRESH     23505
V-50(N,NP+D)TI-49       STABLE            THRESH     23505
V-50(N,NA)SC-46         *                 THRESH     23506
V-50(N,T)TI-48          *                 THRESH     23507
V-50(N,HE-3)SC-48       182.      D       THRESH     23509
V-51(N,2N)V-50          4.   E+16 Y       THRESH     23511
V-51(N,P)TI-51          5.76      M       THRESH     23513
V-51(N,A)SC-48          1.82      D       THRESH     23514
V-51(N,NP+D)TI-50       STABLE            THRESH     23515
V-51(N,NP+D)TI-50       STABLE            THRESH     23515
V-51(N,NA)SC-47         3.35      D       THRESH     23516
V-51(N,T)TI-49          STABLE            THRESH     23517
V-51(N,HE-3)SC-49       57.5      M       THRESH     23519
CR-50(N,2N)CR-49        41.8      M       THRESH     24501
CR-50(N,P)V-50          4.   E+16 Y       THRESH     24503
CR-50(N,A)TI-47         STABLE            THRESH     24504
CR-50(N,NP+D)V-49       331.      D       THRESH     24505
CR-50(N,NP+D)V-49       331.      D       THRESH     24505
CR-50(N,NA)TI-46        STABLE            THRESH     24506
CR-50(N,T)V-48          16.13     D       THRESH     24507
CR-50(N,HE-3)TI-48      STABLE            THRESH     24509
CR-51(N,2N)CR-50        STABLE            THRESH     24511
CR-51(N,P)V-51          STABLE            THRESH     24513
CR-51(N,A)TI-48         16.13     D       THRESH     24514
CR-51(N,NP+D)V-50       4.   E+16 Y       THRESH     24515
CR-51(N,NA)TI-47        STABLE            THRESH     24516
CR-52(N,2N)CR-51        27.8      D       THRESH     24521
CR-52(N,P)V-52          3.75      M       THRESH     24523
CR-52(N,A)TI-49         STABLE            THRESH     24524
CR-52(N,NP+D)V-51       STABLE            THRESH     24525
CR-52(N,NP+D)V-51       STABLE            THRESH     24525
CR-52(N,NA)TI-48        STABLE            THRESH     24526
CR-52(N,T)V-50          4.   E+16 Y       THRESH     24527
CR-52(N,HE-3)TI-50      STABLE            THRESH     24529
CR-53(N,2N)CR-52        STABLE            THRESH     24531
CR-53(N,P)V-53          2.0       M       THRESH     24533
CR-53(N,A)TI-50         STABLE            THRESH     24534
CR-53(N,NP+D)V-52       3.75      M       THRESH     24535
CR-53(N,NP+D)V-52       3.75      M       THRESH     24535
CR-53(N,NA)TI-49        STABLE            THRESH     24536
CR-53(N,T)V-51          STABLE            THRESH     24537
CR-53(N,HE-3)TI-51      5.76      M       THRESH     24539
CR-54(N,2N)CR-53        STABLE            THRESH     24541
CR-54(N,P)V-54          55.       S       THRESH     24543
CR-54(N,A)TI-51         5.76      M       THRESH     24544
CR-54(N,NP+D)V-53       2.0       M       THRESH     24545
CR-54(N,NP+D)V-53       2.0       M       THRESH     24545
CR-54(N,NA)TI-50        STABLE            THRESH     24546
CR-54(N,T)V-52          3.75      M       THRESH     24547
CR-54(N,HE-3)TI-52      *                 THRESH     24549
MN-53(N,2N)MN-52        *                 THRESH     25531
MN-53(N,P)CR-53         STABLE            THRESH     25533
MN-53(N,A)V-50          4.    E+16Y       THRESH     25534
MN-53(N,NP+D)CR-52      STABLE            THRESH     25535
MN-53(N,NA)V-49         331.      D       THRESH     25536
MN-54(N,2N)MN-53        2.    E+6 Y       THRESH     25541
MN-54(N,P)CR-54         STABLE            THRESH     25543
MN-54(N,A)V-51          STABLE            THRESH     25544
MN-54(N,NP+D)CR-53      STABLE            THRESH     25545
MN-54(N,NP+D)CR-53      STABLE            THRESH     25545
MN-54(N,NA)V-50         4.   E+16 Y       THRESH     25546
MN-54(N,T)CR-52         STABLE            THRESH     25547
MN-54(N,HE-3)V-52       3.75      M       THRESH     25549
MN-55(N,2N)MN-54        313.      D       ENDF/B-3   25551
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MN-55(N,G)MN-56          2.6       H       ENDF/B-3   25552
MN-55(N,P)CR-55          3.5       M       ENDF/B-3   25553
MN-55(N,A)V-52           3.8       M       ENDF/B-3   25554
FE-54(N,2N)FE-53         *                 THRESH     26541
FE-54(N,P)MN-54          313.      D       UKAEA233   26543
FE-54(N,P)MN-54          313.      DOBSOLETUKAEA-63   26543
FE-54(N,P)MN-54          313.      D       THRESH     26543
FE-54(N,A)CR-51          28.       D       THRESH     26544
FE-54(N,NP+D)MN-53       2.    E+6 Y       THRESH     26545
FE-54(N,NP+D)MN-53       2.    E+6 Y       THRESH     26545
FE-54(N,NA)CR-50         STABLE            THRESH     26546
FE-54(N,T)MN-52          *                 THRESH     26547
FE-54(N,HE-3)CR-52       STABLE            THRESH     26549
FE-55(N,2N)FE-54         STABLE            THRESH     26551
FE-55(N,P)MN-55          STABLE            THRESH     26553
FE-55(N,A)CR-52          STABLE            THRESH     26554
FE-55(N,NP+D)MN-54       313.      D       THRESH     26555
FE-55(N,NA)CR-51         27.8      D       THRESH     26556
FE-56(N,2N)FE-55         2.7       Y       THRESH     26561
FE-56(N,P)MN-56          2.6       H       UKAEA234   26563
FE-56(N,P)MN-56          2.6       HOBSOLETUKAEA-98   26563
FE-56(N,P)MN-56          2.58      HOBSOLETUKAEA-62   26563
FE-56(N,P)MN-56          2.582     H       THRESH     26563
FE-56(N,A)CR-53          STABLE            THRESH     26564
FE-56(N,NP+D)MN-55       STABLE            THRESH     26565
FE-56(N,NP+D)MN-55       STABLE            THRESH     26565
FE-56(N,NA)CR-52         STABLE            THRESH     26566
FE-56(N,T)MN-54          313.      D       THRESH     26567
FE-56(N,HE-3)CR-54       STABLE            THRESH     26569
FE-57(N,2N)FE-56         STABLE            THRESH     26571
FE-57(N,P)MN-57          1.7       M       THRESH     26573
FE-57(N,A)CR-54          STABLE            THRESH     26574
FE-57(N,NP+D)MN-56       2.58      H       THRESH     26575
FE-57(N,NP+D)MN-56       2.582     H       THRESH     26575
FE-57(N,NA)CR-53         STABLE            THRESH     26576
FE-57(N,T)MN-55          STABLE            THRESH     26577
FE-57(N,HE-3)CR-55       3.53      M       THRESH     26579
FE-58(N,2N)FE-57         STABLE            THRESH     26581
FE-58(N,P)MN-58          1.1       M       THRESH     26583
FE-58(N,A)CR-55          3.53      M       THRESH     26584
FE-58(N,NP+D)MN-57       1.7       M       THRESH     26585
FE-58(N,NP+D)MN-57       1.7       M       THRESH     26585
FE-58(N,NA)CR-54         STABLE            THRESH     26586
FE-58(N,T)MN-56          2.58      H       THRESH     26587
FE-58(N,HE-3)CR-56       5.9       M       THRESH     26589
CO-57(N,2N)CO-56         77.3      D       THRESH     27571
CO-57(N,P)FE-57          *                 THRESH     27573
CO-57(N,A)MN-54          313.      D       THRESH     27574
CO-57(N,NP+D)FE-56       STABLE            THRESH     27575
CO-57(N,NA)MN-53         2.    E+6 Y       THRESH     27576
CO-59(N,2N)CO-58         71.       D       ENDF/B-3   27591
CO-59(N,G)CO-60          5.27      Y       ENDF/B-3   27592
CO-59(N,P)FE-59          45.       D       ENDF/B-3   27593
CO-59(N,A)MN-56          2.6       H       ENDF/B-3   27594
CO-60(N,2N)CO-59         STABLE            THRESH     27601
CO-60(N,P)FE-60          1.    E+5 Y       THRESH     27603
CO-60(N,A)MN-57          1.7       M       THRESH     27604
CO-60(N,NP+D)FE-59       45.       D       THRESH     27605
CO-60(N,NP+D)FE-59       45.       D       THRESH     27605
CO-60(N,NA)MN-56         2.58      H       THRESH     27606
CO-60(N,T)FE-58          STABLE            THRESH     27607
CO-60(N,HE-3)MN-58       1.1       M       THRESH     27609
NI-58(N,2N)NI-57         36.       H       UKAEA      28581
NI-58(N,2N)NI-57         6.2       D       THRESH     28581
NI-58(N,P)CO-58          *                 THRESH     28583
NI-58(N,A)FE-55          2.7       Y       THRESH     28584
NI-58(N,NP+D)CO-57       271.      D       THRESH     28585
NI-58(N,NP+D)CO-57       271.      D       THRESH     28585
NI-58(N,NA)FE-54         STABLE            THRESH     28586
NI-58(N,T)CO-56          77.3      D       THRESH     28587
NI-58(N,HE-3)FE-56       STABLE            THRESH     28589
NI-59(N,2N)NI-58         STABLE            THRESH     28591
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NI-59(N,P)CO-59          STABLE             THRESH     28593
NI-59(N,A)FE-56          STABLE             THRESH     28594
NI-59(N,NP+D)CO-58       *                  THRESH     28595
NI-59(N,NA)FE-55         2.7          Y     THRESH     28596
NI-60(N,2N)NI-59         8.     E+6   Y     THRESH     28601
NI-60(N,P)CO-60          *                  THRESH     28603
NI-60(N,A)FE-57          STABLE             THRESH     28604
NI-60(N,NP+D)CO-59       STABLE             THRESH     28605
NI-60(N,NP+D)CO-59       STABLE             THRESH     28605
NI-60(N,NA)FE-56         STABLE             THRESH     28606
NI-60(N,T)CO-58          *                  THRESH     28607
NI-60(N,HE-3)FE-58       STABLE             THRESH     28609
NI-61(N,2N)NI-60         STABLE             THRESH     28611
NI-61(N,P)CO-61          1.65         H     THRESH     28613
NI-61(N,A)FE-58          STABLE             THRESH     28614
NI-61(N,NP+D)CO-60       *                  THRESH     28615
NI-61(N,NP+D)CO-60       *                  THRESH     28615
NI-61(N,NA)FE-57         STABLE             THRESH     28616
NI-61(N,T)CO-59          STABLE             THRESH     28617
NI-61(N,HE-3)FE-59       45           D     THRESH     28619
NI-62(N,2N)NI-61         STABLE             THRESH     28621
NI-62(N,P)CO-62          *                  THRESH     28623
NI-62(N,A)FE-59          45.          D     THRESH     28624
NI-62(N,NP+D)CO-61       1.65         H     THRESH     28625
NI-62(N,NP+D)CO-61       1.65         H     THRESH     28625
NI-62(N,NA)FE-58         STABLE             THRESH     28626
NI-62(N,T)CO-60          *                  THRESH     28627
NI-62(N,HE-3)FE-60       1.     E+5   Y     THRESH     28629
NI-63(N,2N)NI-62         STABLE             THRESH     28631
NI-63(N,P)CO-63          52.          S     THRESH     28633
NI-63(N,A)FE-60          1.     E+5   Y     THRESH     28634
NI-63(N,NP+D)CO-62       *                  THRESH     28635
NI-63(N,NP+D)CO-62       *                  THRESH     28635
NI-63(N,NA)FE-59         45.          D     THRESH     28636
NI-63(N,T)CO-61          1.65         H     THRESH     28637
NI-63(N,HE-3)FE-61       6.06         M     THRESH     28639
NI-64(N,2N)NI-63         92.          Y     THRESH     28641
NI-64(N,P)CO-64          *                  THRESH     28643
NI-64(N,A)FE-61          6.06         M     THRESH     28644
NI-64(N,NP+D)CO-63       52.          S     THRESH     28645
NI-64(N,NP+D)CO-63       52.          S     THRESH     28645
NI-64(N,NA)FE-60         1.     E+5   Y     THRESH     28646
NI-64(N,T)CO-62          *                  THRESH     28647
CU-63(N,2N)CU-62         9.8          M     ENDF/B-3   29631
CU-63(N,G)CU-64          12.8         H     ENDF/B-3   29632
CU-63(N,P)NI-63          92.          Y     ENDF/B-3   29633
CU-63(N,A)CO-60          5.27         Y     ENDF/B-3   29634
CU-65(N,2N)CU-64         12.8         H     ENDF/B-3   29651
CU-65(N,G)CU-66          5.1          M     ENDF/B-3   29652
CU-65(N,P)NI-65          2.6          H     ENDF/B-3   29653
CU-65(N,A)CO-62          13.9         M     ENDF/B-3   29654
Y-89(N,2N)Y-88           107.         D     UKAEA      39891
Y-89(N,2N)Y-88           *                  THRESH     39891
Y-89(N,G)Y-90            *                  COOK       39892
Y-89(N,P)SR-89           50.8         D     THRESH     39893
Y-89(N,A)RB-86           *                  THRESH     39894
Y-89(N,NP+D)SR-88        STABLE             THRESH     39895
Y-89(N,NP+D)SR-88        STABLE             THRESH     39895
Y-89(N,NA)RB-85          STABLE             THRESH     39896
Y-89(N,T)SR-87           *                  THRESH     39897
Y-89(N,HE-3)RB-87        5.    E+10   Y     THRESH     39899
Y-90(N,2N)Y-89           *                  THRESH     39901
Y-90(N,G)Y-91            *                  COOK       39902
Y-90(N,P)SR-90           28.9         Y     THRESH     39903
Y-90(N,A)RB-87           5.    E+10   Y     THRESH     39904
Y-90(N,NP+D)SR-89        50.8         D     THRESH     39905
Y-90(N,NP+D)SR-89        50.8         D     THRESH     39905
Y-90(N,NA)RB-86          *                  THRESH     39906
Y-90(N,T)SR-88           STABLE             THRESH     39907
Y-90(N,HE-3)RB-88        17.7         M     THRESH     39909
Y-91(N,2N)Y-90           *                  THRESH     39911
Y-91(N,G)Y-92            3.53         H     COOK       39912
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Y-91(N,P)SR-91	9.67	H	THRESH	39913
Y-91(N,A)RB-88	17.7	M	THRESH	39914
Y-91(N,NP+D)SR-90	28.9	Y	THRESH	39915
Y-91(N,NP+D)SR-90	28.9	Y	THRESH	39915
Y-91(N,NA)RB-87	5.0 E+10	Y	THRESH	39916
Y-91(N,T)SR-89	50.8	D	THRESH	39917
Y-91(N,HE-3)RB-89	15.2	M	THRESH	39919
ZR-90(N,2N)ZR-89	79.	H	UKAEA	40901
ZR-90(N,2N)ZR-89	*		THRESH	40901
ZR-90(N,G)ZR-91	STABLE		COOK	40902
ZR-90(N,P)Y-90	*		THRESH	40903
ZR-90(N,A)SR-87	*		THRESH	40904
ZR-90(N,NP+D)Y-89	*		THRESH	40905
ZR-90(N,NP+D)Y-89	*		THRESH	40905
ZR-90(N,NA)SR-86	STABLE		THRESH	40906
ZR-90(N,T)Y-88	*		THRESH	40907
ZR-90(N,HE-3)SR-88	STABLE		THRESH	40909
ZR-91(N,2N)ZR-90	*		THRESH	40911
ZR-91(N,G)ZR-92	STABLE		COOK	40912
ZR-91(N,P)Y-91	*		THRESH	40913
ZR-91(N,A)SR-88	STABLE		THRESH	40914
ZR-91(N,NP+D)Y-90	*		THRESH	40915
ZR-91(N,NP+D)Y-90	*		THRESH	40915
ZR-91(N,NA)SR-87	*		THRESH	40916
ZR-91(N,T)Y-89	*		THRESH	40917
ZR-91(N,HE-3)SR-89	50.8	D	THRESH	40919
ZR-92(N,2N)ZR-91	STABLE		THRESH	40921
ZR-92(N,G)ZR-93	9.5 E+5	Y	COOK	40922
ZR-92(N,P)Y-92	3.53	H	THRESH	40923
ZR-92(N,A)SR-89	50.8	D	THRESH	40924
ZR-92(N,NP+D)Y-91	*		THRESH	40925
ZR-92(N,NP+D)Y-91	*		THRESH	40925
ZR-92(N,NA)SR-88	STABLE		THRESH	40926
ZR-92(N,T)Y-90	*		THRESH	40927
ZR-92(N,HE-3)SR-90	28.9	Y	THRESH	40929
ZR-93(N,2N)ZR-92	STABLE		THRESH	40931
ZR-93(N,G)ZR-94	STABLE		COOK	40932
ZR-93(N,P)Y-93	10.2	H	THRESH	40933
ZR-93(N,A)SR-90	28.9	Y	THRESH	40934
ZR-93(N,NP+D)Y-92	3.53	H	THRESH	40935
ZR-93(N,NP+D)Y-92	3.53	H	THRESH	40935
ZR-93(N,NA)SR-89	50.8	D	THRESH	40936
ZR-93(N,T)Y-91	*		THRESH	40937
ZR-93(N,HE-3)SR-91	9.67	H	THRESH	40939
ZR-94(N,2N)ZR-93	9.5 E+5	Y	THRESH	40941
ZR-94(N,G)ZR-95	STABLE		COOK	40942
ZR-94(N,P)Y-94	20.3	M	THRESH	40943
ZR-94(N,A)SR-91	9.7	H	THRESH	40944
ZR-94(N,NP+D)Y-93	10.2	H	THRESH	40945
ZR-94(N,NP+D)Y-93	10.2	H	THRESH	40945
ZR-94(N,NA)SR-90	28.9	Y	THRESH	40946
ZR-94(N,T)Y-92	3.53	H	THRESH	40947
ZR-94(N,HE-3)SR-92	2.7	H	THRESH	40949
ZR-95(N,2N)ZR-94	STABLE		THRESH	40951
ZR-95(N,G)ZR-96	STABLE		COOK	40952
ZR-95(N,G)ZR-96	STABLE		ENDF/B-3	40952
ZR-95(N,P)Y-95	10.5	M	THRESH	40953
ZR-95(N,A)SR-92	2.7	H	THRESH	40954
ZR-95(N,NP+D)Y-94	20.3	M	THRESH	40955
ZR-95(N,NP+D)Y-94	20.3	M	THRESH	40955
ZR-95(N,NA)SR-91	9.67	H	THRESH	40956
ZR-95(N,T)Y-93	10.2	H	THRESH	40957
ZR-96(N,2N)ZR-95	65.5	D	THRESH	40961
ZR-96(N,G)ZR-97	16.8	H	COOK	40962
ZR-96(N,P)Y-96	2.3	M	THRESH	40963
ZR-96(N,A)SR-93	7.5	M	THRESH	40964
ZR-96(N,NP+D)Y-95	10.5	M	THRESH	40965
ZR-96(N,NP+D)Y-95	10.5	M	THRESH	40965
ZR-96(N,NA)SR-92	2.69	H	THRESH	40966
ZR-96(N,T)Y-94	20.3	M	THRESH	40967
NB-92(N,2N)NB-91	*		THRESH	41921
NB-92(N,P)ZR-92	STABLE		THRESH	41923

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NB-92(N,A)Y-89          *                 THRESH    41924
NB-92(N,NP+D)ZR-91      STABLE            THRESH    41925
NB-92(N,NP+D)ZR-91      STABLE            THRESH    41925
NB-92(N,NA)Y-88         *                 THRESH    41926
NB-92(N,T)ZR-90         *                 THRESH    41927
NB-92(N,HE-3)Y-90       *                 THRESH    41929
NB-93(N,2N)NB-92        *          OBSOLETENDF/B-3  41931
NB-93(N,2N)NB-92        *                 THRESH    41931
NB-93(N,G)NB-94         2.0  E+4  YBG ONLYENDF/B-3  41932
NB-93(N,P)ZR-93         9.5  E+5  Y       ENDF/B-3  41933
NB-93(N,P)ZR-93         9.5  E+5  Y       THRESH    41933
NB-93(N,A)Y-90          64.       H       ENDF/B-3  41934
NB-93(N,A)Y-90          *                 THRESH    41934
NB-93(N,NP+D)ZR-92      STABLE            THRESH    41935
NB-93(N,NP+D)ZR-92      STABLE            THRESH    41935
NB-93(N,NA)Y-89         *                 THRESH    41936
NB-93(N,T)ZR-91         STABLE            THRESH    41937
NB-93(N,HE-3)Y-91       *                 THRESH    41939
NB-94(N,2N)NB-93        *                 THRESH    41941
NB-94(N,P)ZR-94         STABLE            THRESH    41943
NB-94(N,A)SR-91         9.7       H       THRESH    41944
NB-94(N,NP+D)ZR-93      9.5  E+5  Y       THRESH    41945
NB-94(N,NP+D)ZR-93      9.5  E+5  Y       THRESH    41945
NB-94(N,NA)Y-90         *                 THRESH    41946
NB-94(N,T)ZR-92         STABLE            THRESH    41947
NB-94(N,HE-3)Y-92       3.53      H       THRESH    41949
MO-100(N,2N)MO-99       66.6      H       THRESH    42001
MO-100(N,G)MO-101       14.6      M       COOK      42002
MO-100(N,G)MO-101       15.       M       ENDF/B-3  42002
MO-100(N,P)NB-100       *                 THRESH    42003
MO-100(N,A)ZR-97        16.8      H       THRESH    42004
MO-100(N,NP+D)NB-99     *                 THRESH    42005
MO-100(N,NP+D)NB-99     *                 THRESH    42005
MO-100(N,NA)ZR-96       STABLE            THRESH    42006
MO-100(N,T)NB-98        *                 THRESH    42007
MO-92(N,2N)MO-91        *                 THRESH    42921
MO-92(N,G)MO-93         3.   E+3  Y       BENZI     42922
MO-92(N,P)NB-92         *                 THRESH    42923
MO-92(N,A)ZR-89         *                 THRESH    42924
MO-92(N,NP+D)NB-91      *                 THRESH    42925
MO-92(N,NP+D)NB-91      *                 THRESH    42925
MO-92(N,NA)ZR-88        85.       D       THRESH    42926
MO-92(N,T)NB-90         *                 THRESH    42927
MO-92(N,HE-3)ZR-90      STABLE            THRESH    42929
MO-93(N,2N)MO-92        STABLE            THRESH    42931
MO-93(N,P)NB-93         *                 THRESH    42933
MO-93(N,A)ZR-90         *                 THRESH    42934
MO-93(N,NP+D)NB-92      *                 THRESH    42935
MO-93(N,NP+D)NB-92      *                 THRESH    42935
MO-93(N,NA)ZR-89        *                 THRESH    42936
MO-93(N,T)NB-91         *                 THRESH    42937
MO-93(N,HE-3)ZR-91      STABLE            THRESH    42939
MO-94(N,2N)MO-93        *                 THRESH    42941
MO-94(N,G)MO-95         STABLE            BENZI     42942
MO-94(N,P)NB-94         *                 THRESH    42943
MO-94(N,A)ZR-91         STABLE            THRESH    42944
MO-94(N,NP+D)NB-93      *                 THRESH    42945
MO-94(N,NP+D)NB-93      *                 THRESH    42945
MO-94(N,NA)ZR-90        *                 THRESH    42946
MO-94(N,T)NB-92         *                 THRESH    42947
MO-94(N,HE-3)ZR-92      STABLE            THRESH    42949
MO-95(N,2N)MO-94        STABLE            THRESH    42951
MO-95(N,G)MO-96         STABLE            COOK      42952
MO-95(N,G)MO-96         STABLE            ENDF/B-3  42952
MO-95(N,P)NB-95         *                 THRESH    42953
MO-95(N,A)ZR-92         STABLE            THRESH    42954
MO-95(N,NP+D)NB-94      *                 THRESH    42955
MO-95(N,NP+D)NB-94      *                 THRESH    42955
MO-95(N,NA)ZR-91        STABLE            THRESH    42956
MO-95(N,T)NB-93         *                 THRESH    42957
MO-95(N,HE-3)ZR-93      9.5  E+5  Y       THRESH    42959
MO-96(N,2N)MO-95        STABLE            THRESH    42961
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MO-96(N,G)MO-97          STABLE              COOK       42962
MO-96(N,P)NB-96          23.4       H        THRESH     42963
MO-96(N,A)ZR-93          9.5   E+5  Y        THRESH     42964
MO-96(N,NP+D)NB-95       *                   THRESH     42965
MO-96(N,NP+D)NB-95       *                   THRESH     42965
MO-96(N,NA)ZR-92         STABLE              THRESH     42966
MO-96(N,T)NB-94          *                   THRESH     42967
MO-96(N,HE-3)ZR-94       STABLE              THRESH     42969
MO-97(N,2N)MO-96         STABLE              THRESH     42971
MO-97(N,G)MO-98          STABLE              COOK       42972
MO-97(N,G)MO-98          STABLE              ENDF/B-3   42972
MO-97(N,P)NB-97          *                   THRESH     42973
MO-97(N,A)ZR-94          STABLE              THRESH     42974
MO-97(N,NP+D)NB-96       23.4       H        THRESH     42975
MO-97(N,NP+D)NB-96       23.4       H        THRESH     42975
MO-97(N,NA)ZR-93         9.5   E+5  Y        THRESH     42976
MO-97(N,T)NB-95          *                   THRESH     42977
MO-97(N,HE-3)ZR-95       65.5       D        THRESH     42979
MO-98(N,2N)MO-97         STABLE              THRESH     42981
MO-98(N,G)MO-99          66.6       H        COOK       42982
MO-98(N,G)MO-99          67.        H        ENDF/B-3   42982
MO-98(N,P)NB-98          *                   THRESH     42983
MO-98(N,A)ZR-95          65.5       D        THRESH     42984
MO-98(N,NP+D)NB-97       *                   THRESH     42985
MO-98(N,NP+D)NB-97       *                   THRESH     42985
MO-98(N,NA)ZR-94         STABLE              THRESH     42986
MO-98(N,T)NB-96          23.4       H        THRESH     42987
MO-98(N,HE-3)ZR-96       STABLE              THRESH     42989
MO-99(N,2N)MO-98         STABLE              THRESH     42991
MO-99(N,G)MO-100         STABLE              COOK       42992
MO-99(N,G)MO-100         STABLE              ENDF/B-3   42992
MO-99(N,P)NB-99          *                   THRESH     42993
MO-99(N,A)ZR-96          STABLE              THRESH     42994
MO-99(N,NP+D)NB-98       *                   THRESH     42995
MO-99(N,NP+D)NB-98       *                   THRESH     42995
MO-99(N,NA)ZR-95         65.5       D        THRESH     42996
MO-99(N,T)NB-97          *                   THRESH     42997
MO-99(N,HE-3)ZR-97       16.8       H        THRESH     42999
TC-97(N,2N)TC-96         *                   THRESH     43971
TC-97(N,P)MO-97          STABLE              THRESH     43973
TC-97(N,A)NB-94          *                   THRESH     43974
TC-97(N,NP+D)MO-96       STABLE              THRESH     43975
TC-97(N,NP+D)MO-96       STABLE              THRESH     43975
TC-97(N,NA)NB-93         *                   THRESH     43976
TC-97(N,T)MO-95          STABLE              THRESH     43977
TC-97(N,HE-3)NB-95       *                   THRESH     43979
TC-98(N,2N)TC-97         *                   THRESH     43981
TC-98(N,P)MO-98          STABLE              THRESH     43983
TC-98(N,A)NB-95          *                   THRESH     43984
TC-98(N,NP+D)MO-97       STABLE              THRESH     43985
TC-98(N,NP+D)MO-97       STABLE              THRESH     43985
TC-98(N,NA)NB-94         *                   THRESH     43986
TC-98(N,T)MO-96          STABLE              THRESH     43987
TC-98(N,HE-3)NB-96       23.4       H        THRESH     43989
TC-99(N,2N)TC-98         1.5   E+6  Y        ENDF/B-3   43991
TC-99(N,2N)TC-98         1.5   E+6  Y        THRESH     43991
TC-99(N,G)TC-100         15.9       S        COOK       43992
TD-99(N,G)TC-100         16.        S        ENDF/B-3   43992
TC-99(N,P)MO-99          66.6       H        THRESH     43993
TC-99(N,A)NB-96          23.4       H        THRESH     43994
TC-99(N,NP+D)MO-98       STABLE              THRESH     43995
TC-99(N,NP+D)MO-98       STABLE              THRESH     43995
TC-99(N,NA)NB-95         *                   THRESH     43996
TC-99(N,T)MO-97          STABLE              THRESH     43997
TC-99(N,HE-3)NB-97       *                   THRESH     43999
RU-104(N,G)RU-105        4.44       H        COOK       44042
SN-112(N,2N)SN-111       35.1       M        THRESH     50121
SN-112(N,G)SN-113        115.       D        BENZI      50122
SN-112(N,P)IN-112        *                   THRESH     50123
SN-112(N,A)CD-109        *                   THRESH     50124
SN-112(N,NP+D)IN-111     *                   THRESH     50125
SN-112(N,NP+D)IN-111     *                   THRESH     50125
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SN-112(N,NA)CD-108	*		THRESH	50126
SN-112(N,T)IN-110	*		THRESH	50127
SN-112(N,HE-3)CD-110	STABLE		THRESH	50129
SN-114(N,2N)SN-113	*		THRESH	50141
SN-114(N,G)SN-115	STABLE		BENZI	50142
SN-114(N,P)IN-114	*		THRESH	50143
SN-114(N,A)CD-111	*		THRESH	50144
SN-114(N,NP+D)IN-113	*		THRESH	50145
SN-114(N,NP+D)IN-113	*		THRESH	50145
SN-114(N,NA)CD-110	STABLE		THRESH	50146
SN-114(N,T)IN-112	*		THRESH	50147
SN-114(N,HE-3)CD-112	STABLE		THRESH	50149
SN-115(N,2N)SN-114	STABLE		THRESH	50151
SN-115(N,G)SN-116	STABLE		COOK	50152
SN-115(N,P)IN-115	*		THRESH	50153
SN-115(N,A)CD-112	STABLE		THRESH	50154
SN-115(N,NP+D)IN-114	*		THRESH	50155
SN-115(N,NP+D)IN-114	*		THRESH	50155
SN-115(N,NA)CD-111	*		THRESH	50156
SN-115(N,T)IN-113	*		THRESH	50157
SN-115(N,HE-3)CD-113	*		THRESH	50159
SN-116(N,2N)SN-115	*		THRESH	50161
SN-116(N,G)SN-117	*		COOK	50162
SN-116(N,P)IN-116	*		THRESH	50163
SN-116(N,A)CD-113	*		THRESH	50164
SN-116(N,NP+D)IN-115	*		THRESH	50165
SN-116(N,NP+D)IN-115	*		THRESH	50165
SN-116(N,NA)CD-112	STABLE		THRESH	50166
SN-116(N,T)IN-114	*		THRESH	50167
SN-116(N,HE-3)CD-114	STABLE		THRESH	50169
SN-117(N,2N)SN-116	STABLE		THRESH	50171
SN-117(N,G)SN-118	STABLE		COOK	50172
SN-117(N,P)IN-117	*		THRESH	50173
SN-117(N,A)CD-114	STABLE		THRESH	50174
SN-117(N,NP+D)IN-116	*		THRESH	50175
SN-117(N,NP+D)IN-116	*		THRESH	50175
SN-117(N,NA)CD-113	*		THRESH	50176
SN-117(N,T)IN-115	*		THRESH	50177
SN-117(N,HE-3)CD-115	*		THRESH	50179
SN-118(N,2N)SN-117	*		THRESH	50181
SN-118(N,G)SN-119	*		COOK	50182
SN-118(N,P)IN-118	*		THRESH	50183
SN-118(N,A)CD-115	*		THRESH	50184
SN-118(N,NP+D)IN-117	*		THRESH	50185
SN-118(N,NP+D)IN-117	*		THRESH	50185
SN-118(N,NA)CD-114	STABLE		THRESH	50186
SN-118(N,T)IN-116	*		THRESH	50187
SN-118(N,HE-3)CD-116	STABLE		THRESH	50189
SN-119(N,2N)SN-118	*		THRESH	50191
SN-119(N,G)SN-120	STABLE		COOK	50192
SN-119(N,P)IN-119	*		THRESH	50193
SN-119(N,A)CD-116	STABLE		THRESH	50194
SN-119(N,NP+D)IN-118	*		THRESH	50195
SN-119(N,NP+D)IN-118	*		THRESH	50195
SN-119(N,NA)CD-115	*		THRESH	50196
SN-119(N,T)IN-117	*		THRESH	50197
SN-120(N,2N)SN-119	*		THRESH	50201
SN-120(N,P)IN-120	*		THRESH	50203
SN-120(N,G)SN-121	*		COOK	50204
SN-120(N,A)CD-117	*		THRESH	50204
SN-120(N,NP+D)IN-119	*		THRESH	50205
SN-120(N,NP+D)IN-119	*		THRESH	50205
SN-120(N,NA)CD-116	STABLE		THRESH	50206
SN-120(N,T)IN-118	*		THRESH	50207
SN-122(N,2N)SN-121	*		THRESH	50221
SN-122(N,G)SN-123	*		COOK	50222
SN-122(N,P)IN-122	8.	S	THRESH	50223
SN-122(N,A)CD-119	*		THRESH	50224
SN-122(N,NP+D)IN-121	*		THRESH	50225
SN-122(N,NP+D)IN-121	*		THRESH	50225
SN-122(N,NA)CD-118	49.	M	THRESH	50226
SN-122(N,T)IN-120	*		THRESH	50227

SN-124(N,2N)SN-123	*			THRESH	50241
SN-124(N,P)IN-124	4.		S	THRESH	50243
SN-124(N,NP+D)IN-123	*			THRESH	50245
SN-124(N,NP+D)IN-123	*			THRESH	50245
SN-124(N,T)IN-122	8.		S	THRESH	50247
SN-124(N,G)SN-125	*			COOK	50252
TA-181(N,2N)TA-180	600.		D	ENDF/B-3	73811
TA-181(N,2N)TA-180	*			THRESH	73811
TA-181(N,G)TA-182	115.		D	ENDF/B-3	73812
TA-181(N,P)HF-181	42.4		D	THRESH	73813
TA-181(N,A)LU-178	28.		M	ENDF/B-3	73814
TA-181(N,A)LU-178	*			THRESH	73814
TA-181(N,NP+D)HF-180	*			THRESH	73815
TA-181(N,NP+D)HF-180	*			THRESH	73815
TA-181(N,NA)LU-177	*			THRESH	73816
TA-181(N,T)HF-179	*			THRESH	73817
TA-181(N,HE-3)LU-179	4.6		H	THRESH	73819
W-182(N,2N)W-181	121.		D	ENDF/B-3	74821
W-182(N,2N)W-181	*			THRESH	74821
W-182(N,G)W-183	STABLE		GS+ISO.	ENDF/B-3	74822
W-182(N,P)TA-182	115.		D	ENDF/B-3	74823
W-182(N,P)TA-182	9.	E+6	Y	THRESH	74823
W-182(N,A)HF-179	*			THRESH	74824
W-182(N,NP+D)TA-181	*			THRESH	74825
W-182(N,NP+D)TA-181	*			THRESH	74825
W-182(N,NA)HF-178	*			THRESH	74826
W-182(N,T)TA-180	*			THRESH	74827
W-182(N,HE-3)HF-180	*			THRESH	74829
W-183(N,2N)W-182	STABLE			ENDF/B-3	74831
W-183(N,2N)W-182	STABLE			THRESH	74831
W-183(N,G)W-184	STABLE			ENDF/B-3	74832
W-183(N,P)TA-183	5.0		D	ENDF/B-3	74833
W-183(N,P)TA-183	5.		D	THRESH	74833
W-183(N,A)HF-180	*			THRESH	74834
W-183(N,NP+D)TA-182	*			THRESH	74835
W-183(N,NP+D)TA-182	*			THRESH	74835
W-183(N,NA)HF-179	*			THRESH	74836
W-183(N,T)TA-181	*			THRESH	74837
W-183(N,HF-3)HF-181	42.4		D	THRESH	74839
W-184(N,2N)W-183	STABLE			ENDF/B-3	74841
W-184(N,2N)W-183	*			THRESH	74841
W-184(N,G)W-185	75.		D	ENDF/B-3	74842
W-184(N,P)TA-184	8.7		H	ENDF/B-3	74843
W-184(N,P)TA-184	8.7		H	THRESH	74843
W-184(N,A)HF-181	42.4		D	THRESH	74844
W-184(N,NP+D)TA-183	5.		D	THRESH	74845
W-184(N,NP+D)TA-183	5.0		D	THRESH	74845
W-184(N,NA)HF-180	*			THRESH	74846
W-184(N,T)TA-182	*			THRESH	74847
W-184(N,HE-3)HF-182	9.	E+6	Y	THRESH	74849
W-186(N,2N)W-185	75.		D	ENDF/B-3	74861
W-186(N,2N)W-185	*			THRESH	74861
W-186(N,G)W-187	24.		H	ENDF/B-3	74862
W-186(N,P)TA-186	11.		M	ENDF/B-3	74863
W-186(N,P)TA-186	10.6		M	THRESH	74863
W-186(N,A)HF-183	*			THRESH	74864
W-186(N,NP+D)TA-185	49.		M	THRESH	74865
W-186(N,NP+D)TA-185	49.		M	THRESH	74865
W-186(N,NA)HF-182	9.	E+6	Y	THRESH	74866
W-186(N,T)TA-184	8.7		H	THRESH	74867
PB-204(N,2N)PB-203	*			THRESH	82041
PB-204(N,P)TL-202	*			THRESH	82043
PB-204(N,A)HG-201	*			THRESH	82044
PB-204(N,NP+D)TL-203	STABLE			THRESH	82045
PB-204(N,NP+D)TL-203	STABLE			THRESH	82045
PB-204(N,NA)HG-200	STABLE			THRESH	82046
PB-204(N,T)TL-202	*			THRESH	82047
PB-204(N,HE-3)HG-202	STABLE			THRESH	82049
PB-206(N,2N)PB-205	*			THRESH	82061
PB-206(N,P)TL-206	*			THRESH	82063
PB-206(N,A)HG-203	*			THRESH	82064
PB-206(N,NP+D)TL-205	STABLE			THRESH	82065

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PB-206(N,NP+D)TL-205   STABLE                THRESH    82065
PB-206(N,NA)HG-202     STABLE                THRESH    82066
PB-206(N,T)TL-204      *                     THRESH    82067
PB-206(N,HE-3)HG-204   STABLE                THRESH    82069
PB-207(N,2N)PB-206     *                     THRESH    82071
PB-207(N,P)TL-207      *                     THRESH    82073
PB-207(N,A)HG-204      STABLE                THRESH    82074
PB-207(N,NP+D)TL-206   *                     THRESH    82075
PB-207(N,NP+D)TL-206   4.21        M         THRESH    82075
PB-207(N,NA)HG-203     *                     THRESH    82076
PB-207(N,T)TL-205      STABLE                THRESH    82077
PB-208(N,2N)PB-207     *                     THRESH    82081
PB-208(N,P)TL-208      *                     THRESH    82083
PB-208(N,A)HG-205      5.5         M         THRESH    82084
PB-208(N,NP+D)TL-207   *                     THRESH    82085
PB-208(N,NP+D)TL-207   *                     THRESH    82085
PB-208(N,NA)HG-204     STABLE                THRESH    82086
PB-208(N,T)TL-206      *                     THRESH    82087
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IV. ENDF/B-IV YIELD, DECAY, AND CROSS-SECTION FILES (T. R. England and N. L. Whittemore)

A. Yields, $\overline{\nu}_p$, $\overline{\nu}_d$

The fissionable nuclide charge would be exactly conserved by the fission products (i.e., by a yield weighting of the product charges) if all independent yield data were exact. Similarly, yield weightings along with delayed neutron emission probabilities can be used to estimate prompt and delayed neutrons per fission ($\overline{\nu}_p$, $\overline{\nu}_d$) and various other quantities as an integral test of yield data. The preliminary ENDF/B-IV yields did not conserve charge, a result of an error in a General Electric (GE) code. LASL, Hanford Engineering Development Laboratory (HEDL), and GE cooperated in revising and checking the yield data.

The basis for the yield data has been described in previous progress reports. Table IV summarizes the number of independent yields per fissionable nuclide and energy now in the files.

TABLE IV

ENDF/B-IV YIELD CONTENT[a]
(Masses 72 → 167, Charges 26 → 70)

No. of Yields	Fissionable Nuclide	← Energy →		
		Thermal	Fast	~ 14 MeV
1130	^{235}U	X	X	X
1130	^{238}U		X	X
1146	^{239}Pu	X	X	
1146	^{241}Pu	X		
1097	^{233}U	X		
1130	^{232}Th		X	

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[a] Direct, or Independent Yields

Table V lists the weightings obtained using the revised yields in a local code prepared for processing ENDF/B-IV yields. These results can be used to estimate several quantities. All yields now sum to 200%.

Table VI lists the changes in charge balance, prompt and delayed neutrons per fission found for the preliminary and final ENDF/B-IV files. The delayed neutron calculations required the additional input of neutron emission probabilities for 57 nuclides.

Charge balance is now within the assumed error of ± 0.1 charge units of the most probable charge per fission, Z_p. The largest deviation (+ 0.07 units) occurs for the ^{235}U 14-MeV yields. Charge balance is off only 0.008 units for ^{235}U thermal fission.

Delayed neutrons per fission now exhibit the general energy dependence found experimentally, namely, that the yield is essentially constant up to second chance fission. In addition, the quantitative agreement with experiment is also improved for most of the ten yield sets. Uranium-238 fast fission has worsened.

Delayed neutron calculations for each precursor, fissionable nuclide, and each delayed group have been distributed to interested members of the Cross Section Evaluation Working Group (CSEWG) Decay Data Task Force.

Readable listings of independent and cumulative yields and their fractions of each total mass yield have been processed for use in the CINDER code.

B. Decay and Absorption Data

A processing code was written to extract basic nuclide decay parameters from a preliminary ENDF/B-IV tape. This was combined with (n,γ) branching fractions and thermal and resoance cross sections to form a very compact data listing covering 825 nuclides. The result will be used to determine all linear chains needed to describe the time-dependence of fission products.

The final input format of LASL processed data for use in a revised form of CINDER-7 has been determined by LASL and Bettis Atomic Power Laboratory (BAPL).

TABLE V

ENDF/B-IV FINAL YIELD WEIGHTINGS

Fissionable Nuclide	Average Charge No. $\sum_i y_i Z_i$	Average Stable Mass $\sum_j y_j MS_j$	Average Neutron No. $\sum_i y_i N_i$	Average Mass No. $\sum_i y_i A_i$	Average Stable Charge No. $\sum_j y_j ZS_j$
^{235}U(T)	9.20077E+01	2.33411E+02	1.41589E+02	2.33597E+02	9.80818E+01
^{235}U(F)	9.20148E+01	2.33447E+02	1.41618E+02	2.33633E+02	9.80840E+01
^{235}U(HE)	9.20731E+01	2.32257E+02	1.40371E+02	2.32444E+02	9.76128E+01
^{238}U(F)	9.20298E+01	2.36143E+02	1.44299E+02	2.36329E+02	9.92165E+01
^{238}U(HE)	9.20704E+01	2.34860E+02	1.42977E+02	2.35047E+02	9.86443E+01
^{239}Pu(T)	9.40148E+01	2.36906E+02	1.43077E+02	2.37092E+02	9.94858E+01
^{239}Pu(F)	9.40053E+01	2.37047E+02	1.43228E+02	2.37234E+02	9.95331E+01
^{241}Pu(T)	9.40054E+01	2.38822E+02	1.45003E+02	2.39009E+02	1.00266E+02
^{233}U(T)	9.20027E+01	2.31346E+02	1.39529E+02	2.31532E+02	9.72075E+01
^{232}Th(F)	9.00134E+01	2.30443E+02	1.40614E+02	2.30628E+02	9.68762E+01

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y_i = Direct Yield

Y_j = Mass Chain Yield

Z_i = Charge (of Direct Yield)

ZS_j = Most Stable Charge, Mass j

A_i = Neutron No. (of Direct Yield)

MS_j = Mass of Most Stable Charge Mass Chain j

NOTE: Following the nuclide, T, F, and HE denote thermal, fast, and 14-MeV neutron fission energies.

TABLE VI

CHANGE FROM PRELIMINARY (1/74) TO FINAL (8/74) CHARGE AND $\bar{\nu}$ VALUES CALCULATED FROM ENDF/B-IV YIELDS AND DELAYED NEUTRON EMISSION PROBABILITIES

Nuclide	% Error in Charge Balance		$\bar{\nu}_p$		$\bar{\nu}_d$	
	Initial	Final	Initial	Final	Initial	Final
^{235}U(T)	0.041	0.008	2.429	2.411	0.0157	0.0158
^{235}U(F)	0.245	0.016	2.641	2.382	0.0105	0.0146
^{235}U(HE)	0.008	0.079	3.607	3.629	0.0123	0.0107
^{238}U(F)	0.072	0.032	2.628	2.701	0.0309	0.0285
^{238}U(HE)	0.261	0.076	4.199	4.023	0.0171	0.0189
^{239}Pu(T)	0.061	0.016	2.852	2.923	0.0056	0.0052
^{239}Pu(F)	0.352	0.006	3.145	2.772	0.0032	0.0051
^{241}Pu(T)	0.031	0.006	3.045	2.997	0.0098	0.0103
^{233}U(T)	0.027	0.003	2.474	2.471	0.0080	0.0082
^{232}Th(F)	0.628	0.015	2.393	2.386	0.0295	0.0388

V. CINDER-7 (T. R. England and N. L. Whittemore)

This code is now operational at LASL. It is variably dimensioned, has a free-form input format, uses dynamic storage, and is capable of computing γ-spectra as exhibited in the last progress report. Several new I/O options have been incorporated into this version.

In cooperation with BAPL and Knolls Atomic Power Laboratory (KAPL), this version is to be extensively modified to eliminate redundant data input and to further reduce required memory size; the changes along with the existing variable dimensioning should permit calculations of decay heat, absorption buildup, and γ-spectra using the total ensemble of fission and activation products. Such calculations and coding are needed for comparison with the decay heat experiments now in progress at LASL, various uses in LASL's HTGR safety analysis program, proposed disposal studies of high-level waste products, and for use in meeting specific Atomic Energy Commission Division of Physical Research, Division of Reactor Research and Development, and Defense Nuclear Agency commitments.

Currently, CINDER-7 is tied to CDC-processors. K. H. Witte (LASL C-3) has recently removed most machine dependence from the code. It is now being debugged. This version will also be tested during the next quarter at BAPL and KAPL.

VI. ANS 5.1 DECAY HEAT STANDARD (T. R. England)

A new American Nuclear Society (ANS) working group was formed in July for the purpose of reviewing, updating, and extending the current decay heat standard to include other fuels and fission neutron energies. Currently the standard applies only to $^{235}U + n_{th}$.

On August 26, 1974, the first meeting of this group was held for the specific purpose of "laying out a general approach and approximate time table for the development of an improved and more comprehensive standard for fission product decay heat." Initial membership of this group consists of V. E. Schrock, Chairman, University of California, Berkeley; T. R. England, LASL; G. J. Scatena, GE, San Jose; R. E. Schenter, HEDL; K. Shure, BAPL; and C. R. Weisbin, ORNL.

No formal action was taken, but there was general agreement that the basis for the present standard would not support any significant reduction in its uncertainty, and that extension to other fuels and irradiation spectra and histories was needed. There were suggestions but no final decision as to the final form of the extended standard.

VII. EVALUATION OF ACTIVATION AND TOTAL (n,2n) CROSS SECTIONS FOR ^{93}Nb (C. Philis [Centre d'Etudes de Bruyères-le-Châtel, Montrouge, France] and P. G. Young)

Preliminary evaluations of the total (n,2n) cross section of ^{93}Nb and of the ^{93}Nb(n,2n) activation cross section leading to the metastable first excited state of ^{92}Nb have been completed for neutron energies between threshold and 20 MeV. All available experimental data were assembled for the evaluation and were carefully examined for sources of error. Where sufficient information was available, the measurements were renormalized to modern standards and a set of recommended values and errors was determined from the corrected measurements. Measurements for which insufficient information was available for renormalization were treated either as relative or were not included in the evaluation.

To analyze the activation measurements, we adopted the evaluation of Kokher and Horen[36] for the disintegration scheme of ^{92}Zr following positron decay of the metastable first excited state of ^{92}Nb (E_x = 136 keV, $\Gamma_{1/2}$ = 10.15 days). Although several different reactions were used in the various experiments to determine neutron fluxes, the most frequently used were the ^{27}Al(n,α)^{24}Na reaction in activation measurements and the ^{238}U(n,f) reaction in direct measurements of the total (n,2n) cross section. In our analysis we used the evaluations of Young and Foster[37] and Sowerby et al.[38] as standards for these reactions.

Figure 2 compares the uncorrected experimental data[39-54] (upper half of the figure) for both activation and total (n,2n) measurements with the values obtained after renormalization to consistent standards (lower half). Little adjustment was required for the total (n,2n) measurements, because they are recent and are based on reasonably consistent standards. Significant corrections were required, however, for several of the older activation measurements, and a significant decrease in the "scatter" of the experimental points was accomplished by the renormalizations. The largest correction required

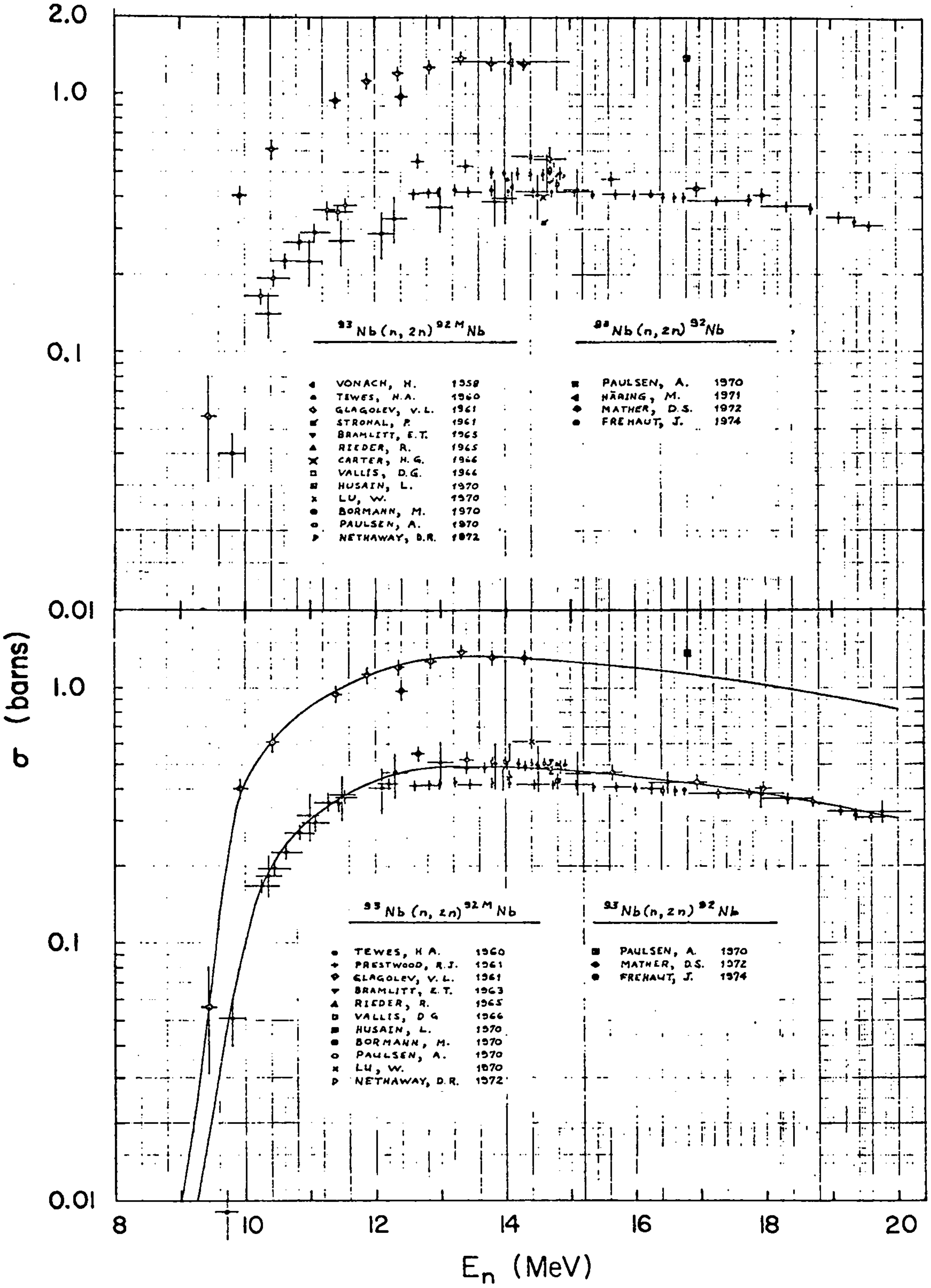

Fig. 2. Experimental data[39-54] for the ^{93}Nb(n,2n)^{92}Nb and ^{93}Nb(n,2n)^{92M}Nb reactions before (upper half of figure) and after (lower half) correction for consistent standards. The solid curves are the results of the evaluation.

was an increase of approximately 40% in the Tewes activation data.[40]

The solid curves in the lower half of Fig. 2 give our recommended values for the activation and total (n,2n) cross sections. The curve for the activation cross section near 14 MeV is based on the Tewes[40] and Paulsen[50] measurements, and above 15 MeV on the Tewes,[40] Paulsen,[50] and Bormann[49] measurements and on the relative data of Prestwood.[55] Note that the Paulsen[50] data near 14 MeV lie about 15% below the evaluated curve.

The recommended curve for the total (n,2n) cross section below 11.5 MeV is based on the direct measurement of Frehaut.[54] Above 11.5 MeV the recommended curve is assumed to have the same shape as the activation curve. The normalization of the curve ($\sigma_{total} = 2.67\ \sigma_{activation}$) was determined from the Frehaut[54] and Mather[53] measurements, which were both performed using large liquid scintillators and are relative to the fission cross section of ^{238}U. The Frehaut and Mather results are in good agreement near 14 MeV but the Mather point at 12.4 MeV lies roughly 25% below the Frehaut results.

VIII. EVALUATION OF THE ^{169}Tm(n,2n)^{168}Tm CROSS SECTION (P. G. Young and C. Philis [Centre d'Etudes de Bruyères-le-Châtel, Montrouge, France])

An evaluation of the nuclear cross section for the ^{169}Tm(n,2n)^{168}Tm reaction has been completed from threshold to 20 MeV. The available experimental data were critically reviewed and were normalized to consistent standards in a manner similar to that described in Section VII for ^{93}Nb(n,2n) reactions.

Figure 3 presents a comparison of the uncorrected ^{169}Tm(n,2n) measurements[40,46,51,53,56-60] (upper half of the figure) with the measurements adjusted to common standards (lower half). As was the case with the ^{93}Nb(n,2n) reaction, the agreement among the various measurements was significantly improved with the standards corrections. It should be noted, however, that the Vallis[46] and Bari[58] points were not included with the corrected data due to lack of standards information, and the Tewes[40] results were treated as relative and were simply renormalized.

The present reaction differs from the ^{93}Nb(n,2n) case in that the activation and direct experiments both measure the same quantity, that is, the total (n,2n) cross section. Because the two methods involve entirely different techniques and standards, it is interesting to compare results from the direct measurements of Mather[53] and Frehaut[60] with the activation results of Dilg,[56] Druzhinin,[57] Nethaway,[51] and Vos.[59] The results obtained with the two techniques appear to be in good agreement in Fig. 3, although there is a tendency for the direct measurements to lie a few percent higher than the activation results. This difference is entirely consistent with uncertainties in the different standards used in the two methods. The direct measurements of Mather[53] and Frehaut[60] agree reasonably near 14 MeV, but the Mather point at 12.4 MeV lies significantly below Frehaut's data, as was the case for ^{93}Nb(n,2n).

The recommended curve is in good agreement from 13-15 MeV with statistical theory calculations by Jary,[61] and the calculations have been used to extend the curve to 20 MeV. The + 2σ uncertainty in the recommended data is estimated to be + 10% near 14 MeV, ± 20% above 16 MeV, and ± 50% below 9 MeV.

IX. MEDIUM ENERGY LIBRARY (D. G. Foster, Jr., G. M. Hale, W. B. Wilson, and D. R. Harris)

Extensive revision of the intranuclear-cascade-plus-evaporation code CROIX is virtually complete. The changes made are required to provide more meaningful results for very light nuclei and energies above a few hundred MeV, where the original CROIX exhibited numerous pathological symptoms. The revised version has been designated CROIX-2.

The cascade module itself is unchanged; it remains equivalent to the MECC-3 code of ORNL. After completion of the cascade, however, the residual nucleus is inspected before beginning evaporation. If it has negative Z or N; is a nucleon, multineutron, or multiproton; has a mass excess greater than 100 MeV (as determined from the revised mass subroutine described in previous reports); or has an excitation energy, E_x, which is negative by more than 2% of the incident energy, the event is rejected and the event counter set back. If E_x is negative by less than 2% the event is accepted and the energies of all the cascade particles are scaled down so as to leave $E_x = 0$. The resulting momentum imbalance is ignored and the evaporation phase is aborted.

The evaporation module has been completely rewritten except for the basic calculations of emission probabilites taken from EVAP-3. However, the

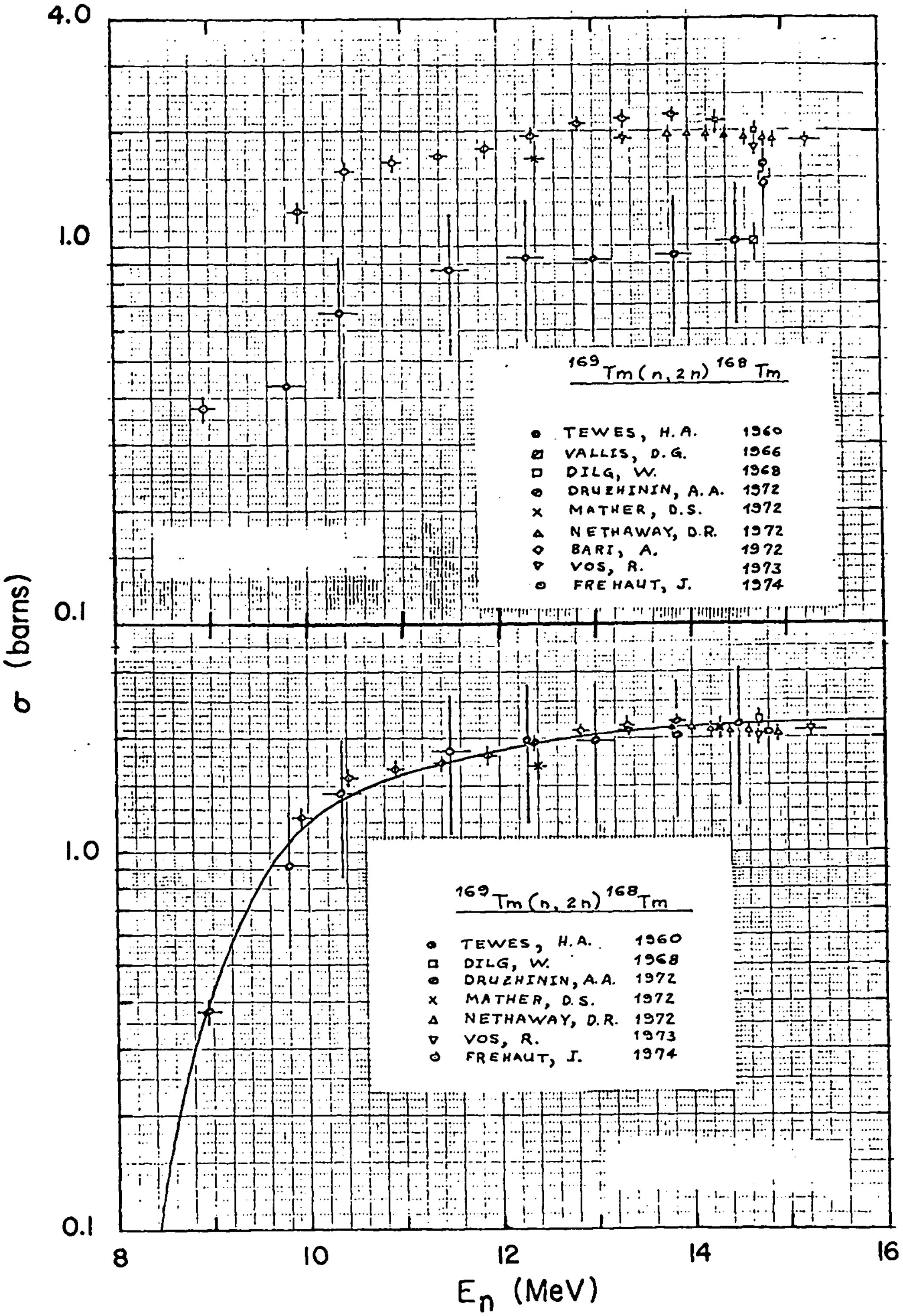

Fig. 3. Experimental data[39,45,50,55-59] for the ^{169}Tm(n,2n)^{168}Tm reaction before (upper half of figure) and after (lower half) correction for consistent standards. The solid curve is the result of the evaluation.

emission probabilities are now calculated correctly using the reduced mass of the system instead of the mass of the emitted particle. Double counting of channels in which the residual nucleus is also an emittable particle has been eliminated. Emission of the evaporated particles is now isotropic in the center-of-mass system instead of the laboratory system and the correct polar angle of emission is retained in the output. The kinematics are exact throughout, except that nonrelativistic mechanics is used instead of relativistic mechanics. The subroutine begins with the actual recoil momentum before evaporation, recalculates the recoil direction in the lab system after each emission, and recomputes the transformation matrix for the next emission. Creation of impossible residual nuclei is prevented. Residual nuclei in the emittable category, none of which have any excited states below their particle-breakup energies, are scrutinized before emission of the corresponding particle is attempted in order to determine whether they will have enough excitation energy to disintegrate further. If not, the entire remaining energy is converted to kinetic energy of the fragments which are then transformed to the lab system with no remaining excitation, and the residual nucleus is set to Z = A = 0. If the channel-energy algorithm fails to select an allowed disintegration energy in five tries, it is backed up by an analytical iterative algorithm which always works, but takes much more computation time than the exponential random-number generator used in the primary algorithm. Since there are some conceptual difficulties in the treatment of the pairing-energy correction, we have not adopted the method used in EVAP-4 of removing the pairing correction for a final try at obtaining an energetically possible emission which was prevented by the pairing correction. However, once a channel has been determined to be open (including the pairing correction) any energetically possible emission is allowed.

CROIX-2 defers any output to the history tape until after an event has been certified as valid. This permits the events with minor overshoots in E_x to be corrected and used, but still prevents accepting an event with a defective evaporation. Since 40% of the events for 800-MeV neutrons on ^{16}O produce overshoots, this represents a major saving in machine time. Later versions of CROIX included on the history tapes the sum of the energies (but not the multiplicities) of charged secondaries heavier than the proton. CROIX-2 also includes the individual energies and (tentatively) direction cosines of these heavier particles, which are of possible interest in dose calculations for thin regions of living tissue. The tape format is such that existing codes can read the tapes without any modification and ignore the added information.

A number of potentially interesting quantities have been added to the printout in CROIX-2. The geometric cross section used in the calculation is both printed and added to the first event on the history tape. The nuclear radius assumed for this is read from a data tape which came originally from ORNL. Multiplicities, average kinetic and excitation energies, and average cosines of the polar angle of production are also displayed for all particles and for the intermediate and final residual nuclei. Various diagnositc summaries have been included to determine the frequency and nature of the pathological events.

No abnormalities other than those provided for as outlined above have been observed in an exhaustive test of 500 events (using 800-MeV neutrons incident on ^{16}O). Some intuitively unreasonable channel probabilities have been observed, but these are caused by approximations in the Dostrovsky form of the evaporation model rather than by coding errors. Better models are available and we are beginning a review of some of them. The transverse direction cosines average to zero as the number of events increases, and the polar cosines are qualitatively reasonable. In the test problem less than 1% of the cascade events are unusable, although about 25% of all interactions leave no residual nucleus after evaporation (that is, the residual nucleus is an alpha particle or lighter and is tabulated as a particle). Energy imbalance caused by the nonrelativistic approximation is normally less than 0.1 MeV, although this approximation does, of course, distort the energy spectra without producing an erroneous overall energy release. Since CROIX-2 lists the starting random numbers for all pathological events, if further problems turn up during production runs, the events can be repeated for detailed diagnosis.

Work has begun on a version of the processor DANA1 to convert the history tapes to processed cross sections in the form required by the National Aeronautic and Space Administration (NASA). Production running of histories for the first four nuclides for NASA is expected to be completed next quarter, and the results processed and shipped. One element from the older history tapes has been transferred to Photostore, and this effort will continue until the entire set of histories for the medium-energy library has been transferred.

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