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URR Computer Code: A Code to Calculate Resonance Neutron Cross-Section Probability Tables, Bondarenko Self-Shielding Factors, and Self-Indication Ratios for Fissile and Fertile Nuclides

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Engineering Physics and Mathematics

URR Computer Code: A Code to Calculate Resonance Neutron Cross-Section Probability Tables, Bondarenko Self-Shielding Factors, and Self-Indication Ratios for Fissile and Fertile Nuclides

L. C. Leal, G. de Saussure, and R. B. Perez

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ABSTRACT

The URR computer code has been developed to calculate cross-section probability tables, Bondarenko self-shielding factors, and self-indication ratios for fertile and fissile isotopes in the unresolved resonance region. Monte Carlo methods are utilized to select appropriate resonance parameters and to compute the cross sections at the desired reference energy.

The neutron cross sections are calculated by the single-level Breit-Wigner formalism with s-, p-, and d-wave contributions. The cross-section probability tables are constructed by sampling the Doppler broadened cross-section.

The various shelf-shielded factors are computed numerically as Lebesgue integrals over the cross-section probability tables.

1. INTRODUCTION

The URR (Unresolved Resonance Region) computer code was developed to study the effect of various assumptions on the statistical distributions of unresolved resonance parameters on self-shielding factors and self-indication ratios. The code uses the Monte Carlo method to compute cross-section probability tables. It then utilizes these tables to compute Bondarenko self-shielding factors and self-indication ratios. Consistent with ENDF/B procedures for the unresolved resonance region, all calculations are done in the single-level Breit-Wigner approximation. The code generates directly the cross-section probability tables at a user-specified energy and temperature from user-provided unresolved resonances parameters; the code does not sample from consecutive points on a statistical ladder, as most other codes of this type do,[1,4] and extend the calculations of self-shielding factors and self-indication ratios for fissile nuclides.

These new features led to an improvement in the efficiency and reliability in the calculation of reactor parameters in the unresolved resonance region.

The code was developed and implemented on a VAX-11/785 computer.

This report describes the program and is also intended to serve as a user guide.

2. CROSS-SECTION FORMULA

The single-level Breit-Wigner formula for the unbroadened capture, fission and total cross sections are given in Table 1. For each series (L, J) (L-neutron orbital angular momentum, J-total angular momentum) contributing to the cross sections, the user must specify the values of L, and $G(L, J)$ (spin statistical factor), the average values of $D(L, J)$ (average level spacing), $GN(L, J)$ (average neutron reduced width), $GC(L, J)$ (gamma width), $FW(L, J)$ (average fission width) and the number of degrees of freedom, $NUM(L, J)$ and $NUF(L, J)$ of the chi-squared distribution laws for $GN(L, J)$ and $FW(L, J)$ respectively. The radiation widths GC are assumed to be constant for a given (L, J)-pair; the nearest neighbor level spacing for a (L, J)-series are assumed to follow a Wigner distribution with average value $D(L, J)$. Correlations of successive spacings implied by the Dyson-Metha Δ_3-statistics[2] are ignored. Only values of $L = 1, 2$ or 3 are assumed to contribute; higher angular-momentum contributions are normally negligible in the resonance region.

Table 1. Unbroadened Cross Section

a. Capture and Fission Cross Section

$$\sigma_{n,c}^{\ell} = \frac{\pi}{k^2} \sum_J g_J \sum_{r=1}^{NR_J} \frac{\Gamma_{nr}\Gamma_{cr}}{(E - E_r)^2 + \frac{\Gamma_r^2}{4}}$$

where c can be capture γ, or fission f.

b. Total Cross Section

$$\sigma_{n,t}^{\ell} = \sigma_{pot} + \frac{\pi}{k^2} \sum_J g_J \sum_{r=1}^{NR_J} \frac{\Gamma_{nr}\left[\Gamma_r \cos 2\varphi_\ell + 2(E - E_r)\sin 2\varphi_\ell\right]}{(E - E_r)^2 + \frac{\Gamma_r^2}{4}}$$

$$\sigma_{pot} = \frac{4\pi}{k^2}(2\ell + 1)\sin^2 \varphi_\ell$$

The symbols have the usual meaning as defined, for instance, in reference 6.

The user must also provide values for the ratio of the mass of nucleus considered to the neutron mass $AWRI$, and for scattering radius AP. These values are used to

compute the potential scattering cross section and the shift and penetration factors. The user also specify IPAIRS, the number of pairs of resonances which contribute to the cross sections at the reference energy. An equal number of resonaces is included below and above the reference energy.

The Doppler broadening of the cross sections is approximated by averaging the unbroadened cross sections over a Maxwellian distribution of velocities. The formalism utilized is the same as that described in MC-2.[3] The formulae for the Doppler-broadened cross sections are given in Table 2.

Table 2. Broadened Cross Section

a. Capture and fission cross section

$$\sigma_{n,c} = \frac{2\pi^{3/2}}{k^2} \sum_J g_J \sum_{r=1}^{NR_J} \frac{\Gamma_{nr}^{(\ell,J)}\Gamma_{cr}^{(\ell,J)}}{\Gamma_r^{(\ell,J)}} \frac{U(x,y)}{\Delta}$$

where c can be capture γ, or fission f.

b. Total cross section

$$\sigma_T^\ell = \sigma_{pot} + \frac{2\pi^{3/2}}{k^2} \sum_J g_J \sum_{r=1}^{NR_J} \Gamma_{nr}^{(\ell,J)} \left(\frac{U(x,y)}{\Delta} \cos 2\varphi_\ell - \frac{V(x,y)}{\Delta} \sin 2\varphi_\ell \right)$$

where $U(x,y)$ and $U(x,y)$ are related to the Voight profiles ψ, χ function, as
$\psi(x,\theta) = \sqrt{\pi} b U(a,b)$
$\chi(x,\theta) = \sqrt{\pi} b V(a,b)$

And Δ is the Doppler width.

3. SAMPLING PROCEDURE

For each (L, J)-series of resonances contributing to the cross sections the spacing surrounding the reference energy is selected from the probability distribution

$$P(x)dx = xW(x)dx \quad , \tag{1}$$

where $W(x)dx$ is the Wigner spacing distribution:

$$W(x)dx = (\pi/2)x \exp(-(\pi/4)x^2)dx \quad , \tag{2}$$

where $x = D/ < D >$ and $< D >$ is the mean spacing $D(L, J)$ of the level series.

The position of the reference energy in the surrouding spacing is selected from a uniform distribution:

$$P(x)dx = dx/s \quad , \tag{3}$$

where s is the width of the spacing.

The reduced neutron widths and fission widths of all the resonances considered are selected from the specified chi-squared distribution. The level spacing, except for the central level spacing discussed above, are selected from a Wigner distribution (Eq. 2).

For each history, the total fission and capture cross sections at the reference energy are obtained by summing the contribution of all the resonance considered.

4. CROSS-SECTION PROBABILITY TABLE

The total capture and fission cross sections at the reference energy are computed with each iteration. The probability distribution for the total cross section is parsed on a table. The number of entries and widths of the probability table can be specified by the users. If no specification is given a default recommended by Otter[4] is used. With the probability PTK of the total cross section falling in the kth interval of the table, the average values of the fission and capture cross sections corresponding to that entry are also stored. The standard deviation of the probability PTK is computed from

$$\sigma = (PTK * (1 - PTK)/NL)^{1/2} \tag{4}$$

where NL is the number of iterations.

5. TRANSMISSION AND SELF-INDICATION SELF-SHIELDING RATIOS

Average transmission, average capture, and average fission self- indication factors for a given thickness n are computed according to the expressions,

$$T(n) = \sum_{k=1}^{NL} \frac{PT(k)}{NL} \exp\left(-n\frac{\sigma_T(k)}{PT(k)}\right) \tag{5}$$

$$S_c(n) = \frac{\sum_{k=1}^{NL} \sigma_c(k) \exp\left(-n\frac{\sigma_T(k)}{PT(k)}\right)}{\sum_{k=1}^{NL} \sigma_c(k)} \tag{6}$$

$$S_f(n) = \frac{\sum_{k=1}^{NL} \sigma_f(k) \exp\left(-n\frac{\sigma_T(k)}{PT(k)}\right)}{\sum_{k=1}^{NL} \sigma_f(k)} \tag{7}$$

6. SELF-SHIELDED CROSS SECTIONS

The self-shielded cross sections are computed for each dilution specified using the Bondarenko[5] formalism.

The expression for the self-shielded capture, fission, and total diluted cross section for a dilution σ_0 is,

$$\sigma_c(\sigma_o) = \frac{\displaystyle\sum_{k=1}^{NL} \frac{\sigma_c(k)}{\left(\frac{\sigma_T(k)}{PT(k)}\right) + \sigma_o}}{\displaystyle\sum_{k=1}^{NL} \frac{PT(k)}{\left(\frac{\sigma_T(k)}{PT(k)}\right) + \sigma_0}} \tag{8}$$

$$\sigma_f(\sigma_o) = \frac{\displaystyle\sum_{k=1}^{NL} \frac{\sigma_f(k_0)}{\left(\frac{\sigma_T(k)}{PT(k)}\right) + \sigma_o}}{\displaystyle\sum_{k=1}^{NL} \frac{PT(k)}{\left(\frac{\sigma_T(k)}{PT(k)}\right) + \sigma_o}} \tag{9}$$

$$\sigma_T(\sigma_o) = \frac{\displaystyle\sum_{k=1}^{NL} \frac{PT(k)}{\left(\frac{\sigma_T(k)}{PT(k)}\right) + \sigma_o}}{\displaystyle\sum_{k=1}^{NL} \frac{PT(k)}{\left(\frac{\sigma_T(k)}{PT(k)} + \sigma_o\right)^2}} - \sigma_o \tag{10}$$

7. REFERENCES

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5. I. I. Bondarenko et al., *Group Constant for Nuclear Reactor Calculations*, Consultant Bureau, New York (1964).

6. Data Format and Procedures for the Evaluated Nuclear Data File, ENDF, revised by R. Kinsey, BNL-NCS-50496 (ENDF-102), Second edition (ENDF/B-V), UC-80 (General Technology-TID-4500).

8. INPUT DESCRIPTION

All variables are entered to the code in free format. In each entry the variables are separated by commas.

The structure of the input is as follows:

1. ACCEPT 100, AW, AWRI, AP, EREF, TEMP, NL, IPAIRS, SEED

where:

AW – Mass number of the isotope.
AWRI – Ratio of the mass of the target nucleus to neutron mass.
AP – Scattering radius in units of 1.0E-12 cm.
EREF – Resonance energy (in eV).
TEMP – Temperature in K units.
NL – Number of iterations.
IPAIRS – Number of pairs of resonance levels which contribute to the cross section at the energy EREF.
SEED – Initial seed for the random number generator

2. ACCEPT 101, L, G, D, G0, GC, FW, NUM, NUF

where:

L – Neutron orbital angular momentum.
G – Spin statistical factor.
D – Average level spacing for resonances with total spin J (in eV)
G0 – Average reduced neutron width (in eV).
GC – Average radiation width (in eV).
FW – Average fission width (in eV).
NUM – Number of degrees of freedom in the neutron width distribution.
NUF – Number of degrees of freedom in the fission width distribution.

Note: Several series of resonance parameters can be given. The last card must be a blank card.

3. ACCEPT 102, CST3, CSC3, CSF3

where:

CST3, CSC3, CSF3 – FILE 3 contribution (in barns) to the total, capture and fission cross sections.

4. ACCEPT 103, NPT, CSMIN, CSMAX

where:

NPT – Number of entries for the construction of the probality table.
CSMIN – Lower limit of the band structure.
CSMAX – Upper limit of the band structure.

Note: For default type a blank card.

5. ACCEPT 104, (SIGDIL(M), M = 1, 10)

where:

SIGDIL(M) – Values of the thicknesses (atoms/barn) for the calculation of the self-indication and trasmission ratios. Up to ten consecutive values are allowed. If the number of thickenesses are less than ten, the last value must be zero.

6. ACCEPT 104, (SIGDIL(M), M = 1, 10)

where:

SIGDIL(M) – Values of the dilution cross section (barn) for the calculation of the Bondarenko partial and transport cross section. Up to ten consecutive values are allowed. If the number of dilution are less than ten, the last value must be zero.

9. OUTPUT DESCRIPTION

Unless otherwise specified by the user the output of URR is contained in a file called OUTPUT.URR. This file contains the value of the probability table as well as the cross-section probability table for the number of entries specified by the input variable NPT. Also the average cross-section self-shielding cross section, transmission, and self-indication ratios are given as output. In Appendix B a sample case is given to illustrate the output of the code.

APPENDIX A. FORTRAN LISTING OF URR

```
*************************  URR COMPUTER CODE  ******************************
*                                                                          *
*                                                                          *
*                                                                          *
*                            INPUT DESCRIPTIONS                            *
*                                                                          *
* 1. ACCEPT 100, AW, AWRI, AP, EREF, TEMP, NL, IPAIRS, SEED                *
*                                                                          *
*    Where:                                                                *
*                                                                          *
*    AW - Mass number of the isotope.                                      *
*                                                                          *
*    AWRI - Ratio of the mass of the target nucleus to neutron mass.       *
*                                                                          *
*    AP - Scattering radius in units of 1.0E-12 cm.                        *
*                                                                          *
*    EREF - Resonance energy (in eV).                                      *
*                                                                          *
*    TEMP - Temperature in K units.                                        *
*                                                                          *
*    NL - Number of iterations.                                            *
*                                                                          *
*    IPAIRS - Number of pairs of resonance levels which contribute to the  *
*             cross section at the energy EREF.                            *
*                                                                          *
*    SEED   - Initial seed for the random number generator.                *
*                                                                          *
* 2. ACCEPT 101, L, G, D, GO, GC, FW, NUM, NUF                             *
*                                                                          *
*    Where:                                                                *
*                                                                          *
*    L - Neutron orbital angular momentum.                                 *
*                                                                          *
*    G - Spin statistical factor.                                          *
*                                                                          *
*    D - Average level spacing for resonances with total spin J (in eV)    *
*                                                                          *
*    GO - Average reduced neutron width (in eV).                           *
*                                                                          *
*    GC - Average radiation width (in eV).                                 *
*                                                                          *
*    FW - Average fission width (in eV).                                   *
*                                                                          *
*    NUM - Number of degrees of freedom in the neutron width distribution. *
*                                                                          *
*    NUF - Number of degrees of freedom in the fission width distribution. *
*                                                                          *
*    Note: Several series of resonance can be given. The last card must be *
*          a blank card.                                                   *
*                                                                          *
* 3. ACCEPT 102, CST3, CSC3, CSF3                                          *
*                                                                          *
*    Where:                                                                *
*                                                                          *
*    CST3, CSC3, CSF3 - FILE 3 contribution (in barns) to the total,       *
*                       capture and fission cross sections.                *
```

```
*                                                                      *
* 4. ACCEPT 103, NPT, CSMIN, CSMAX                                     *
*                                                                      *
*    Where:                                                            *
*                                                                      *
*    NPT - Number of entries for the construction of the probality table.  *
*                                                                      *
*    CSMIN - Lower limit of the band structure.                        *
*                                                                      *
*    CSMAX - Upper limit of the band structure.                        *
*                                                                      *
*    Note: For default type a blank card.                              *
*                                                                      *
* 5. ACCEPT 104, ( SIGDIL(M), M = 1, 10 )                              *
*                                                                      *
*    Where:                                                            *
*                                                                      *
*    SIGDIL(M) - Values of the thicknesses (atoms/barn) for the calculation  *
*                of the self-indication and transmission ratios.  Up to ten  *
*                consecutive values are allowed.  If the number of thicknesses*
*                are less than ten, the last value must be zero.       *
*                                                                      *
* 6. ACCEPT 104, ( SIGDIL(M), M = 1, 10 )                              *
*                                                                      *
*    Where:                                                            *
*                                                                      *
*    SIGDIL(M) - Values of the dilution cross section (barn) for the   *
*                calculation of the Bondarenko partial and transport cross  *
*                section.  Up to ten consecutive values are allowed.  If the  *
*                number of dilution are less than ten, the last value must be *
*                zero.                                                 *
************************************************************************
      CHARACTER*30 FIN
      DIMENSION V(3),SIN2FI(3),COS2FI(3)
      DIMENSION LS(6),GS(6),DS(6),GN(6),GG(6),GF(6),NN(6),NF(6)
      DIMENSION PT(50),CSTK(50),CSCK(50),CSFK(50)
      DIMENSION XI(20)
      DIMENSION SIGDIL(10)
      INTEGER*4 SEED
      COMMON SEED
      TYPE *,'Output file name. (Default is OUTPUT.URR) '
      ACCEPT '(A)', FIN
      OPEN(UNIT=1, FILE = FIN, STATUS = 'NEW',
     * DEFAULTFILE = 'OUTPUT.URR')
      SIGN = 1.0
      AKO = 0.002196771
      FOURPI = 12.56637
      ROOTPI = 1.772454
      CTP = 1.128379
      AKB = 3.44672E-4
C
      TYPE *,'TYPE AW, AWRI, AP, EREF, TEMP, NL, IPAIRS,
     * SEED'
      ACCEPT 100, AW, AWRI, AP, EREF, TEMP, NL, IPAIRS, SEED
C
      IF( IPAIRS .EQ .0 )   IPAIRS = 1
C
      WRITE(1, 1000)
      WRITE(1, 1001) AW, AWRI, AP, EREF, TEMP, NL, IPAIRS
C
      RTEREF = SQRT(EREF)
```

```
      AK = AKO * RTEREF * AWRI / (AWRI + 1.0)
      A = 0.123 * AWRI**0.333333 + 0.08
      RHO = AK*A
      RHOSQ = RHO * RHO
      RHO4 = RHOSQ * RHOSQ
      V(1) = 1.0
      V(2) = RHOSQ / (1.0 + RHOSQ)
      V(3) = RHO4 / (9.0 + 3.0 * RHOSQ + RHO4)
      RHOHAT = AK * AP
      C4 = FOURPI /(AK * AK)
      CSP = 0.0
C
C     Compute potential scattering and phase factors
C
      DO 1 LP = 1, 3
        AL = LP - 1
        IF(LP .EQ. 1)   FI = RHOHAT
        IF(LP .EQ. 2)   FI = RHOHAT - ATAN(RHOHAT)
        IF(LP .EQ. 3)   FI = RHOHAT - ATAN(3.0 *
     1  RHOHAT/(3.0 - RHOHAT * RHOHAT))
        CSP = CSP +(AL + AL + 1.0) * C4 * SIN(FI) * SIN(FI)
        TWOFI = FI + FI
        SIN2FI(LP) = SIN(TWOFI)
        COS2FI(LP) = COS(TWOFI)
 1    CONTINUE
      DELTA = SQRT(AKB * TEMP * EREF / AW)
      IF ( TEMP .EQ. 0.0 ) THEN
C
C     Set coeficients for unbroadened cross sections
C
        DEN = 1.0
        CO = C4 / 4.0
      ELSE
C
C     Set coeficients for broadening cross sections
C
        DEN = DELTA
        TWODEL = DELTA + DELTA
        CO = ROOTPI * C4 / TWODEL
      ENDIF
C
C     Read unresolved resonance parameters and FILE 3 Contributions
C
      WRITE(1, 1002)
      CSD = 0.0
      JS = 0
C
      TYPE *,'Type L, G, D, GO, GC, FW, NUM, NUF (D=0 => end data)'
C
 2    CONTINUE
C
      ACCEPT 101, L, G, D, GO, GC, FW, NUN, NUF
C
      IF(D .EQ. 0.0) GO TO 3
      IF(NUN .EQ. 0) NUN = 1
C
      WRITE(1, 1003) L, G, D, GO, GC, FW, NUN, NUF
C
C     Normalization factors ( Gaussian & Chi-squared distribution )
C
      GO = GO / NUN
```

```
      IF(NUF .NE. 0) FW = FW / NUF
C
      JS = JS + 1
      LS(JS) = L + 1
      GS(JS) = G
      DS(JS) = CTP * D / DEN
      GG(JS) = GC
      GN(JS) = GO * V(L+1) * RTEREF
      GF(JS) = FW
      NN(JS) = NUN
      NF(JS) = NUF
      TGAM = GG(JS) + GN(JS) + GF(JS)
      CSD = CSD + G * GN(JS) / TGAM
      GO TO 2
 3    CONTINUE
C
      TYPE *,'Enter with FILE 3 Contribution: CST3, CSC3, CSF3'
      ACCEPT 102, CST3, CSC3, CSF3
C
      WRITE(1, 1004) CST3, CSC3, CSF3
C
C
C     Read probability-table limits or a blank card for default value.
C     Default value calculated according to J. H. Otter et all.
C     (AI-AEC-13024)
C
      TYPE *,'Type NPT, CSMIN, CSMAX or zero for default value'
      ACCEPT 103, NPT, CSMIN, CSMAX
C
      IF(NPT .LE. 0)   NPT = 22
      TMP = 0.2
      IF(LS(2) .EQ. 1)   TMP = 0.7
      IF(CSMIN .LE. 0.0)   CSMIN = TMP * CSP + CST3
      IF(CSMAX .LE. 0.0)   CSMAX = CSP + 6.0 * C4 * CSD + CST3
C
      WRITE(1, 1005)
      WRITE(1, 1006) NPT, CSMIN, CSMAX
C
      ANP = NPT - 2
      TERM = ANP / ALOG(CSMAX/CSMIN)
      ALCSMN = ALOG(CSMIN)
C
C     Initialize probability-table entries
C
      DO 4 K = 1, NPT
        PT(K) = 0.0
        CSTK(K) = 0.0
        CSCK(K) = 0.0
        CSFK(K) = 0.0
 4    CONTINUE
C
C     Loop over number of cases
C
      DO 12 N =1 , NL
        CST = 0.0
        CSC = 0.0
        CSF = 0.0
C
C     Loop over J-L states
C
        DO 8 J = 1, JS
```

```
          X = DS(J) * SQRT(RNMAXF(1.0))
          XI(1) = -X * RAN(SEED)
          XI(2) = X + XI(1)
          LP = LS(J)
          GC = GG(J)
          NUN = NN(J)
          NC2 = NUN + NF(J)
C
C     Two levels per pair
C
          DO 7 IP = 1, 2
            SIGN = -SIGN
C
C     Loop over pairs
C
            DO 7 I = 1, IPAIRS
              IF(I .EQ. 1) X1 = XI(IP)
              IF(I .GT. 1)   X1 = X1 + SIGN * DS(J) *
     *        SQRT(-ALOG(AMAX1(RAN(SEED), 0.00001)))
              G1 = 0.0
              FW = 0.0
              DO 6 NC = 1, NC2
 5              CONTINUE
                R1 = -ALOG(AMAX1(RAN(SEED), 0.00001))
                R2 = -ALOG(AMAX1(RAN(SEED), 0.00001))
                IF( R1 + R1 .LT. (R2-1.) * (R2-1.)) GO TO 5
                IF(NC .LE. NUN) G1 = G1 + R2 * R2 * GN(J)
                IF(NC .GT. NUN) FW = FW + R2 * R2 * GF(J)
 6            CONTINUE
              T1 = GC + G1 + FW
              IF ( TEMP .EQ. 0.0 ) THEN
C
C     Unbroadened cross sections
C
                TPT = X1 * X1 + T1 * T1 / 4.0
                CST = CST + G1 * ( T1 * COS2FI(LP) - 2.0 * X1 *
     *          SIN2FI(LP) ) * GS(J) / TPT
                CSC = CSC + G1 * GC * GS(J) / TPT
                CSF = CSF + G1 * FW * GS(J) / TPT
              ELSE
C
C     Broadened cross sections
C
                Y1 = T1 / TWODEL
                CALL SVS(X1, Y1, U1, V1)
                CST = CST + G1 * (U1 * COS2FI(LP) - V1 * SIN2FI(LP)) *
     *          GS(J)
                CSC = CSC + GC * G1 * U1 * GS(J) / T1
                CSF = CSF + FW * G1 * U1 * GS(J) / T1
              END IF
 7          CONTINUE
 8        CONTINUE
          CST = CSP + CO * CST + CST3
          CSC = CO * CSC + CSC3
          CSF = CO * CSF + CSF3
          IF(CST .LE. CSMIN) GO TO 9
          IF(CST .GE. CSMAX) GO TO 10
          K = TERM * (ALOG(CST) - ALCSMN) + 2
          GO TO 11
 9        CONTINUE
          K = 1
```

```
          GO TO 11
 10       CONTINUE
          K = NPT
 11       CONTINUE
          PT(K) = PT(K) + 1.0
          CSTK(K) = CSTK(K) + CST
          CSCK(K) = CSCK(K) + CSC
          CSFK(K) = CSFK(K) + CSF
 12     CONTINUE
C
C   Construct probability-table, compute average cross-sections
C
        CSTB = 0.0
        CSCB = 0.0
        CSFB = 0.0
        CSTV = 0.0
        CSCV = 0.0
        CSFV = 0.0
        ANL = NL
C
        WRITE(1,1007)
C
        DO 13 K = 1, NPT
          IF(PT(K) .LE. 0.0 .OR. PT(K) .GE. ANL) GO TO 13
          PTK = PT(K)
          CST = CSTK(K)/PTK
          CSC = CSCK(K)/PTK
          CSF = CSFK(K)/PTK
          PTK = PTK/ANL
          PVK = PTK * (1.0 - PTK)/ANL
          PEK = SQRT(PVK)
          CSTB = CSTB + PTK * CST
          CSCB = CSCB + PTK * CSC
          CSFB = CSFB + PTK * CSF
          CSTV = CSTV + PTK * CST * CST
          CSCV = CSCV + PTK * CSC * CSC
          CSFV = CSFV + PTK * CSF * CSF
          CSTK(K) = CST
          CSCK(K) = CSC
          CSFK(K) = CSF
          PT(K) = PTK
C
          WRITE(1,1008) K, PTK, PEK, CST, CSC, CSF
C
 13     CONTINUE
        CSTV = (CSTV - CSTB * CSTB)/ANL
        CSCV = (CSCV - CSCB * CSCB)/ANL
        CSFV = (CSFV - CSFB * CSFB)/ANL
        CSTE = SQRT(CSTV)
        CSCE = SQRT(CSCV)
        CSFE = SQRT(CSFV)
C
        WRITE(1,1009) CSTB, CSTE, CSCB, CSCE, CSFB, CSFE
C
C
C       Calculation of self-indication and transmission ratios
C
C
        TYPE *,'Type thicknesses. Up to ten values or a blank card if it i
       *s not needed.'
        ACCEPT 104, (SIGDIL(M), M = 1, 10)
```

```
C
      IF(SIGDIL(1) .EQ. 0.0) GO TO 17
C
      WRITE(1,1011)
C
C
C     Loop over transmisions
C
C
      DO 16 M = 1, 10
        SIGO = SIGDIL(M)
        IF(SIGO .EQ. 0.0) GO TO 16
        ANUM = 0.0
        ADEN = 0.0
        TRM0 = 0.0
        TRM1 = 0.0
        TRM2 = 0.0
        FNUM = 0.0
        FDEN = 0.0
        FRM0 = 0.0
        FRM1 = 0.0
        FRM2 = 0.0
        TRAN = 0.0
        TRN2 = 0.0
C
C
C       Loop over probability-table entries
C
C
        DO 14 K = 1, NPT
          PTK = PT(K)
          IF(PTK .EQ. 0.0) GO TO 14
          CST = CSTK(K)
          CSC = CSCK(K)
          CSF = CSFK(K)
          EXPT = EXP(-SIGO * CST)
          TERM = PTK * CSC
          FERM = PTK * CSF
          ANUM = ANUM + TERM * EXPT
          FNUM = FNUM + FERM * EXPT
          ADEN = ADEN + TERM
          FDEN = FDEN + FERM
          TRMT = PTK * EXPT
          TRAN = TRAN + TRMT
          TSQR = TERM * CSC
          FSQR = FERM * CSF
          TRM0 = TRM0 + TSQR
          FRM0 = FRM0 + FSQR
          TRM1 = TRM1 + TSQR * EXPT
          FRM1 = FRM1 + FSQR * EXPT
          TRM2 = TRM2 + TSQR * EXPT * EXPT
          FRM2 = FRM2 + FSQR * EXPT * EXPT
          TRN2 = TRN2 + TRMT * EXPT
 14     CONTINUE
        ETR = SQRT((TRN2 - TRAN * TRAN)/ANL)
        SSCSC = ANUM/ADEN
        VAR = (TRM2 + SSCSC * SSCSC * TRM0 -
     *  (SSCSC + SSCSC) * TRM1)/(ADEN * ADEN * ANL)
        ER = SQRT(VAR)
        IF(FDEN .EQ. 0.0) GO TO 15
        SSFSC = FNUM/FDEN
```

```
        VFR = (FRM2 + SSFSC * SSFSC * FRMO -
     *  (SSFSC + SSFSC) * FRM1)/(FDEN * FDEN * ANL)
        FR = SQRT(VFR)
 15     CONTINUE
C
        WRITE(1,1012) SIGO, SSCSC, ER, SSFSC, FR, TRAN, ETR
C
 16   CONTINUE
C
 17   CONTINUE
C
C     Calculation of Bondarenko partial and transport cross sections
C
      TYPE *,'Type sigma dilutions. Up to ten values or a blank card if
     * it is not needed.'
      ACCEPT 104, (SIGDIL(M), M = 1, 10)
C
      IF(SIGDIL(1).EQ.0.)   GO TO 20
C
      WRITE(1, 1013)
C
C     Loop over dilutions
C
      DO 19 M = 1, 10
        SIGO = SIGDIL(M)
        IF(SIGO .EQ. 0.0) GO TO 19
        ANUM = 0.0
        FNUM = 0.0
        ADEN = 0.0
        TRMO = 0.0
        TRM1 = 0.0
        TRF1 = 0.0
        TRM2 = 0.0
        TRF2 = 0.0
        ANUT = 0.0
        ADET = 0.0
        CST1 = 0.0
        CST2 = 0.0
C
C       Loop over probability-table entries
C
        DO 18 K = 1, NPT
          PTK = PT(K)
          IF(PTK .EQ. 0.0) GO TO 18
          CST = CSTK(K)
          CSC = CSCK(K)
          CSF = CSFK(K)
          TERM = PTK/(CST + SIGO)
          ANUM = ANUM + TERM * CSC
          FNUM = FNUM + TERM * CSF
          ADEN = ADEN + TERM
          TSQR = TERM/(CST + SIGO)
          ANUT = ANUT + TERM
          ADET = ADET + TSQR
          TRMO = TRMO + TSQR
          TRM1 = TRM1 + TSQR * CSC
          TRF1 = TRF1 + TSQR * CSF
          TRM2 = TRM2 + TSQR * CSC * CSC
          TRF2 = TRF2 + TSQR * CSF * CSF
          CST1 = CST1 + CST * PTK
          CST2 = CST2 + CST * CST * PTK
```

```
 18     CONTINUE
        SSCSC = ANUM/ADEN
        SSFSC = FNUM/ADEN
        VAR = (TRM2 + SSCSC * SSCSC * TRM0 -
     *  (SSCSC + SSCSC) * TRM1)/(ADEN * ADEN * ANL)
        VFR = (TRF2 + SSFSC * SSFSC * TRM0 -
     *  (SSFSC + SSFSC) * TRF1)/(ADEN * ADEN * ANL)
        ER = SQRT(VAR)
        FR = SQRT(VFR)
        TRAN = ANUT/ADET - SIG0
        ETR = SQRT((CST2 + TRAN * TRAN -2.0 * TRAN * CST1)/ANL)
C
        WRITE(1,1014) SIG0, SSCSC, ER, SSFSC, FR, TRAN, ETR
C
 19   CONTINUE
 20   CONTINUE
      STOP
C
C     Input format list
C
 100  FORMAT(5F, 3I)
 101  FORMAT(I, 5F, 2I)
 102  FORMAT( 3F )
 103  FORMAT(I, 3F)
 104  FORMAT(10F)
C
C     Output format list
C
 1000 FORMAT('0        AW              AWRI             AP
     * ENER            TEMP         NCASES    NPAIRS')
 1001 FORMAT(1H , 5G16.5, 5I8///)
 1002 FORMAT('0                                                J-STATES'/
     *'       L          G                 D                 GO
     *     GC              FW         NUN NUF')
 1003 FORMAT(I8, 5G17.5, 2I4)
 1004 FORMAT(///'                                        FILE 3 CONTRIBU
     *TIONS'/'            TOTAL              CAPTURE              FISSION
     *' / 3G20.5///)
 1005 FORMAT('0 NUMBER OF PT ENTRIES        CSMIN              CSMAX')
 1006 FORMAT(6X, I8, 5X, 5G20.5///)
 1007 FORMAT('0                                    PROBABILITY-TABLE'//
     *'       K            PK                  ERROR                CST
     *              CSC                  CSF')
 1008 FORMAT(I8, 5G20.5)
 1009 FORMAT(///' AVERAGE TOTAL CROSS SECTION   ',G16.5,'+/-',G16.5/
     *' AVERAGE CAPTURE CROSS SECTION ',G16.5, '+/-',G16.5/
     *' AVERAGE FISSION CROSS SECTION ',G16.5,'+/-',G16.5)
 1010 FORMAT(1H ,7G16.5)
 1011 FORMAT(///'                        SELF INDICATION AND TRANSMISSIO
     *N RATIOS')
 1012 FORMAT(//'                                   THICKNESS ',G16.5/' C
     *APTURE SELF INDICATION RATIO ',G16.5,'+/-',G16.5/' FISSION SELF IN
     *DICATION RATIO ',G16.5,'+/-',G16.5/'                  TRANSMISSION
     * ',G16.5,'+/-',G16.5)
 1013 FORMAT(///'                        SELF SHIELDING CROSS SECTIONS')
 1014 FORMAT(//'                                    DILUTION ',G16.5/' C
     *APTURE CROSS SECTION   ',G16.5,'+/-',G16.5/' FISSION CROSS SECTION
     *   ',G16.5,'+/-',G16.5/' TRANSPORT CROSS SECTION ',G16.5,'+/-'
     *,G16.5)
      END
      SUBROUTINE SVS(A, B, C, D)
```

```
      COMMON/TRTI/ TR(62,62), TI(62,62), AIMW, AX, KI, REW, Y1
      DOUBLE PRECISION A, B, C, D
      DATA K/0/
      IF(K .EQ. 1) GO TO 3
      K = 1
      KI = 1
      X = -0.1
      DO 2 I = 1, 62
        Y = -0.1
        DO 1 J = 1, 62
          CALL W(X, Y, TR(I,J), TI(I,J))
          Y = Y + 0.1
 1      CONTINUE
        X = X + 0.1
 2    CONTINUE
 3    CONTINUE
      AX = A
      Y1 = B
      CALL QUICKW
      C = REW
      D = AIMW
      RETURN
      END
      SUBROUTINE W(REZ,AIM1,REW,AIMW)
C
C     Subroutine W and QUICKW are taken from H. Henryson II et all (MC-2).
C     (ANL-8144)
C
      REW = 0.0
      AIMW = 0.0
      AIMZ = ABS(AIM1)
      IF(REZ) 3, 1, 3
 1    IF(AIM1) 3, 2, 3
 2    REW = 1.0
      RETURN
 3    R2 = REZ * REZ
      AI2 = AIMZ * AIMZ
      ABREZ = ABS(REZ)
      IF(ABREZ + 1.25 * AIMZ - 5.0) 6, 6, 4
 4    IF(ABREZ + 1.1 * AIMZ - 6.6) 21, 21, 20
 5    IF(ABREZ + 1.43333 * AIMZ - 4.3) 23, 23, 22
 6    IF(ABREZ + 1.863636 * AIMZ - 4.1) 15, 15, 8
 7    IF(AIMZ - 1.5) 14, 24, 24
 8    IF(AIMZ - 1.4) 19, 19, 5
 9    IF(ABREZ + 1.07317 * AIMZ - 4.4) 23, 23, 22
 10   IF(ABREZ - 2.7) 31, 32, 32
 11   IF(ABREZ - 3.1) 10, 12, 12
 12   IF(ABREZ - 3.4) 33, 34, 34
 13   IF(R2 + 1.18 * AI2 - 5.76) 7, 11, 11
 14   IF(R2 + 1.7227 * AI2 - 4.41) 29, 30, 30
 15   IF(R2 + 1.71 * AI2 - 2.89) 17, 13, 13
 16   IF(R2 + 1.69 * AI2 - 1.69) 27, 28, 28
 17   IF(R2 + 2.0408 * AI2 - 1.0) 18, 16, 16
 18   IF(R2 + 1.5625 * AI2 - 0.25) 25, 26, 26
 19   IF(ABREZ + 1.43333 * AIMZ - 4.3) 24, 24, 9
 20   NMAX = 1
      GO TO 36
 21   NMAX = 2
      GO TO 36
 22   NMAX = 3
      GO TO 36
```

```
 23   NMAX = 4
      GO TO 36
 24   NMAX = 6
      GO TO 36
 25   NMAX = 2
      GO TO 35
 26   NMAX = 3
      GO TO 35
 27   NMAX = 4
      GO TO 35
 28   NMAX = 5
      GO TO 35
 29   NMAX = 6
      GO TO 35
 30   NMAX = 7
      GO TO 35
 31   NMAX = 8
      GO TO 35
 32   NMAX = 9
      GO TO 35
 33   NMAX = 10
      GO TO 35
 34   NMAX = 11
 35   KW = 2
      AIMZ = AIM1
      GO TO 44
 36   KW = 1
      IF(AIM1) 37, 38, 38
 37   KW = 2
      AIMZ = AIM1
      GO TO 44
C
C
C WA IS OBTAINED FROM ASYMPTOTIC SERIES
C
C
 38   RV = 2.0 * (R2 - AI2)
      AK = 4.0 * REZ * AIMZ
      EL = AK
      H = 0.0
      B = 0.0
      A = 0.0
      TEMPM = 0.0
      TEMEL = 0.0
      G = 1.0
      C = -1.1283792 * AIMZ
      D = 1.1283792 * REZ
      AM = RV - 1.0
      AAK = 1.0
      K = 0
 39   AJTEMP = 2.0 * AAK
      TEMP4 =(1.0 - AJTEMP) * AJTEMP
      AJP = RV - (4.0 * AAK + 1.0)
      GO TO 51
 40   AAK = AAK + 1.0
      K = K + 1
      PR = REW
      PI = AIMW
 41   AMAGN = TEMPM*TEMPM + TEMEL*TEMEL
      REW = (TEMPC * TEMPM + TEMPD * TEMEL)/AMAGN
      AIMW = (TEMPM * TEMPD - TEMEL * TEMPC)/AMAGN
```

```
      IF(ABS(REW - PR) - 1.E-6) 42, 39, 39
 42   IF(ABS (AIMW - PI) - 1.E-6) 43, 39, 39
 43   RETURN
C
C
C WT IS OBTAINED FROM TAYLOR SERIES
C
C
 44   TEMP1 = R2 + AI2
      TEMP2 = 2.0 * TEMP1 * TEMP1
      AJ = -(R2 - AI2)/TEMP2
      AK = 2.0 * REZ * AIMZ/TEMP2
      C = 0.0
      B = 0.0
      AJSIG = 0.0
      D = 0.0
      JSIG = 0
      G = 0.0
      H = 0.0
      EL = 0.0
      A = 1.0
      AM = 1.0
      SIGP = 1.5
      EXPON = EXP(TEMP2 * AJ)
      EXPC = EXPON * COS(TEMP2 * AK)
      EXPS = -EXPON * SIN(TEMP2 * AK)
      SIG2P = 2.0 * SIGP
 45   AJ4SIG = 4.0 * AJSIG
      AJ4SM1 = AJ4SIG - 1.0
      TEMP3 = 1.0/(AJ4SM1 * (AJ4SIG + 3.0))
      TT4 = SIG2P * (2.0 * AJSIG - 1.0)
      TEMP4 = TT4/(AJ4SM1 * (AJ4SIG + 1.0) * (AJ4SIG - 3.0) * AJ4SM1)
      AJP = AJ + TEMP3
      GO TO 51
 46   AJSIG = AJSIG + 1.0
      JSIG = JSIG + 1
 47   TEMP7 = (AM * AM + EL * EL) * 1.7724539
      REF = (AIMZ * (C * AM + D * EL) - REZ * (AM * D - C * EL))/
     * TEMP7/TEMP1
      AIMF = (AIMZ * (AM * D - C * EL) + REZ *
     * (C * AM +D*EL))/TEMP7/TEMP1
      PR = REW
      PI = AIMW
      REW = EXPC - REF
      AIMW = EXPS - AIMF
      IF(ABS(REW - PR) - 1.E-6) 48, 50, 50
 48   IF(ABS (AIMW - PI) - 1.E-6) 49, 50, 50
 49   RETURN
 50   SIG2P = 2.0 * AJSIG
      GO TO 45
 51   TEMPC = AJP * C + TEMP4 * A - AK * D
      TEMPD = AJP * D + TEMP4 * B + AK * C
      TEMEL = AJP * EL + TEMP4 * H + AK * AM
      TEMPM = AJP * AM + TEMP4 * G - AK * EL
      A = C
      B = D
      G = AM
      H = EL
      C = TEMPC
      D = TEMPD
      AM = TEMPM
```

```
      EL = TEMEL
      IF(ABS(TEMPM) + ABS(TEMEL) - 1.0E15) 53, 52, 52
52    C = 1.0E-15 * C
      D = 1.0E-1 5* D
      AM = 1.0E-15 * AM
      EL = 1.0E-15 * EL
      TEMPC = 1.0E-15 * TEMPC
      TEMPD = 1.0E-15 * TEMPD
      TEMPM = 1.0E-15 * TEMPM
      TEMEL = 1.0E-15 * TEMEL
      GO TO 55
53    IF(ABS(TEMPM) + ABS(TEMEL) - 1.0E-15) 54, 54, 55
54    C = 1.0E15 * C
      D = 1.0E15 * D
      AM = 1.0E15 * AM
      EL = 1.0E15 * EL
      TEMPC = 1.0E15 * TEMPC
      TEMPD = 1.0E15 * TEMPD
      TEMPM = 1.0E15 * TEMPM
      TEMEL = 1.0E15 * TEMEL
55    GO TO(40, 46, 56), KW
56    RETURN
      END
      SUBROUTINE QUICKW
      COMMON/TRTI/ TR(62, 62) ,TI(62,62), AIMW, AX, KI, REW, Y
      AKI = SIGN(1.0, AX)
      X = ABS(AX)
      TEST =X * X + Y * Y
      IF(TEST .LT. 36.0) GO TO 1
      IF(TEST .LT. 144.0) GO TO 4
      IF(TEST .LT. 10000.0) GO TO 6
      A1 = 1.0/(1.7724539 * TEST)
      REW = Y * A1
      IF(KI .GT. 0) AIMW = X * A1 * AKI
      RETURN
1     II = X * 10.0
      JJ = Y * 10.0
      I = II + 2
      J = JJ + 2
      N = J - 1
      P = 10.0 * X - II
      Q = 10.0 * Y - JJ
2     P2 = P * P
      Q2 = Q * Q
      PQ = P * Q
      HP = 0.5 * P
      HQ = 0.5 * Q
      HQ2 = 0.5 * Q2
      HP2 = 0.5 * P2
      A1 = HQ2 - HQ
      A2 = HP2 - HP
      A3 = 1.0 + PQ - P2 - Q2
      A4 = HP2 - PQ + HP
      A5 = HQ2 - PQ + HQ
      REW = A1 * TR(I,N) + A2 * TR(I-1,J) + A3 * TR(I,J) + A4 *
     * TR(I+1,J) + A5 * TR(I,J+1) + PQ * TR(I+1,J+1)
      IF(KI.LE.0) GO TO 8
3     AIMW = A1 * TI(I,N) + A2 * TI(I-1,J) + A3 * TI(I,J) + A4 *
     * TI(I+1,J) + A5 * TI(I,J+1) + PQ * TI(I+1,J+1)
      AIMW = AIMW * AKI
      GO TO 8
```

```
4     A1 = X * X - Y * Y
      A2 = 2.0 * X * Y
      A3 = A2 * A2
      A4 = A1 - 0.2752551
      A5 = A1 - 2.724745
      D1 = 0.5124242/(A4 * A4 + A3)
      D2 = 0.05176536/(A5 * A5 + A3)
      REW = D1 *(A2 * X - A4 * Y) + D2 *(A2 * X - A5 * Y)
      IF(KI .LE. 0) GO TO 8
5     AIMW = D1 * (A4 * X + A2 * Y) + D2 * (A5 * X + A2 * Y)
      AIMW = AIMW * AKI
      GO TO 8
6     A1 = (X * X - Y * Y) * 2.0
      A2 = 4.0 * X * Y
      A4 = A1 - 1.0
      D1 = 1.1283792/(A4 * A4 + A2 * A2)
      REW = D1 * (A2 * X - A4 * Y)
      IF(KI .LE. 0) GO TO 8
7     AIMW = D1 * (A4 * X + A2 * Y)
      AIMW = AIMW * AKI
8     RETURN
      END
      FUNCTION RNMAXF(T)
      DATA FF/0.0/
      INTEGER*4 SEED
      COMMON SEED
      U= EXPRNF(U)
      IF(FF) 3, 1, 3
1     R1 = RAN(SEED)
      R2 = RAN(SEED)
      R1SQ = R1 * R1
      R2SQ = R2 * R2
      RSQ = R1SQ + R2SQ
      IF(RSQ - 1.0) 2, 2, 1
2     W = EXPRNF(W)/RSQ
      FF = 1.0
      RNMAXF = (R2SQ * W + U) * T
      GO TO 4
3     FF = 0.0
      RNMAXF = (R1SQ * W + U) * T
4     RETURN
      END
      FUNCTION EXPRNF(A)
      REAL I
      INTEGER*4 SEED
      COMMON SEED
      I = 0.0
1     X = RAN(SEED)
      Z = X
2     Y = RAN(SEED)
      IF(Z - Y) 5, 5, 3
3     Z = RAN(SEED)
      IF(Z - Y) 2, 4, 4
4     I = I + 1.0
      GO TO 1
5     EXPRNF = X + I
      RETURN
      END
```

APPENDIX B. SAMPLE CASE

a. Listing of Input

```
$RUN URR
Output file name. (Default is OUTPUT.URR)
OUT.DAT
TYPE AW, AWRI, AP, EREF, TEMP, NL, IPAIRS, SEED
235.0,233.0351,0.93811,150.0,300.0,10000,2,19
Type L, G, D, GO, GC, FW, NUM, NUF (D=0 => end data)
0,0.4375,1.39,0.1217E-3,38.0E-03,268.0E-03,1,2
0,0.5625,0.90,0.0914E-3,35.0E-03,226.0E-03,1,2
Enter with FILE 3 Contribution: CST3, CSC3, CSF3
Type NPT, CSNIN, CSMAX or zero for default value
Type thicknesses. Up to ten values or a blank card if it is not needed.
0.0325,0.0
Type sigma dilutions. Up to ten values or a blank card if it is not needed.
100.0,0.0
```

b. Listing of output

```
         AW              AWRI             AP              ENER            TEMP
NCASES    NPAIRS
       235.00          233.04          0.93811          150.00          300.00
10000       2
                                                  J-STATES
       L         G                 D                 GO                GC
FW        NUN NUF
       0      0.43750           1.3900          0.12170E-03      0.38000E-01
0.26800       1   2
       0      0.56250          0.90000          0.91400E-04      0.35000E-01
0.22600       1   2
                                          FILE 3 CONTRIBUTIONS
            TOTAL             CAPTURE                FISSION
         0.00000E+00         0.00000E+00          0.00000E+00
  NUMBER OF PT ENTRIES        CSMIN                CSMAX
            22               7.7397                849.54
                                        PROBABILITY-TABLE
       K            PK                   ERROR                CST                CSC
CSF
       3         0.15800E-01         0.12470E-02          11.921             0.28793
0.86194
       4         0.10930             0.31202E-02          14.086             0.68068
2.4752
       5         0.14050             0.34751E-02          17.662              1.3744
5.2628
       6         0.14240             0.34946E-02          22.310              2.3521
8.7743
       7         0.12640             0.33230E-02          28.153              3.6473
13.287
       8         0.12030             0.32531E-02          35.665              5.3825
18.913
       9         0.10310             0.30409E-02          45.003              7.7592
25.665
      10         0.76100E-01         0.26516E-02          56.891              10.649
34.431
```

```
     11          0.61300E-01          0.23988E-02          71.855              15.199
44.416
     12          0.44600E-01          0.20642E-02          90.872              20.384
57.213
     13          0.31100E-01          0.17359E-02          114.32              27.740
72.302
     14          0.15900E-01          0.12509E-02          144.54              38.276
89.301
     15          0.79000E-02          0.88530E-03          183.20              49.273
113.04
     16          0.35000E-02          0.59057E-03          227.99              71.485
128.53
     17          0.13000E-02          0.36032E-03          283.10              85.399
161.09
     18          0.30000E-03          0.17318E-03          398.92              118.17
225.50
     19          0.20000E-03          0.14141E-03          450.62              189.57
188.60
 AVERAGE TOTAL CROSS SECTION          41.339    +/-     0.34656
 AVERAGE CAPTURE CROSS SECTION        7.4618    +/-     0.10162
 AVERAGE FISSION CROSS SECTION        22.095    +/-     0.22847
                       SELF INDICATION AND TRANSMISSION RATIOS
                                    THICKNESS      0.32500E-01
 CAPTURE SELF INDICATION RATIO       0.15909    +/-     0.23306E-02
 FISSION SELF INDICATION RATIO       0.18470    +/-     0.21449E-02
                 TRANSMISSION        0.36139    +/-     0.19660E-02
                       SELF SHIELDING CROSS SECTIONS
                                    DILUTION       100.00
 CAPTURE CROSS SECTION          5.8873    +/-     0.63333E-01
 FISSION CROSS SECTION          18.263    +/-     0.16308
 TRANSPORT CROSS SECTION        31.754    +/-     0.35958
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