KERNFORSCHUNGSANLAGE JÜLICH GmbH
Institut für Kernphysik

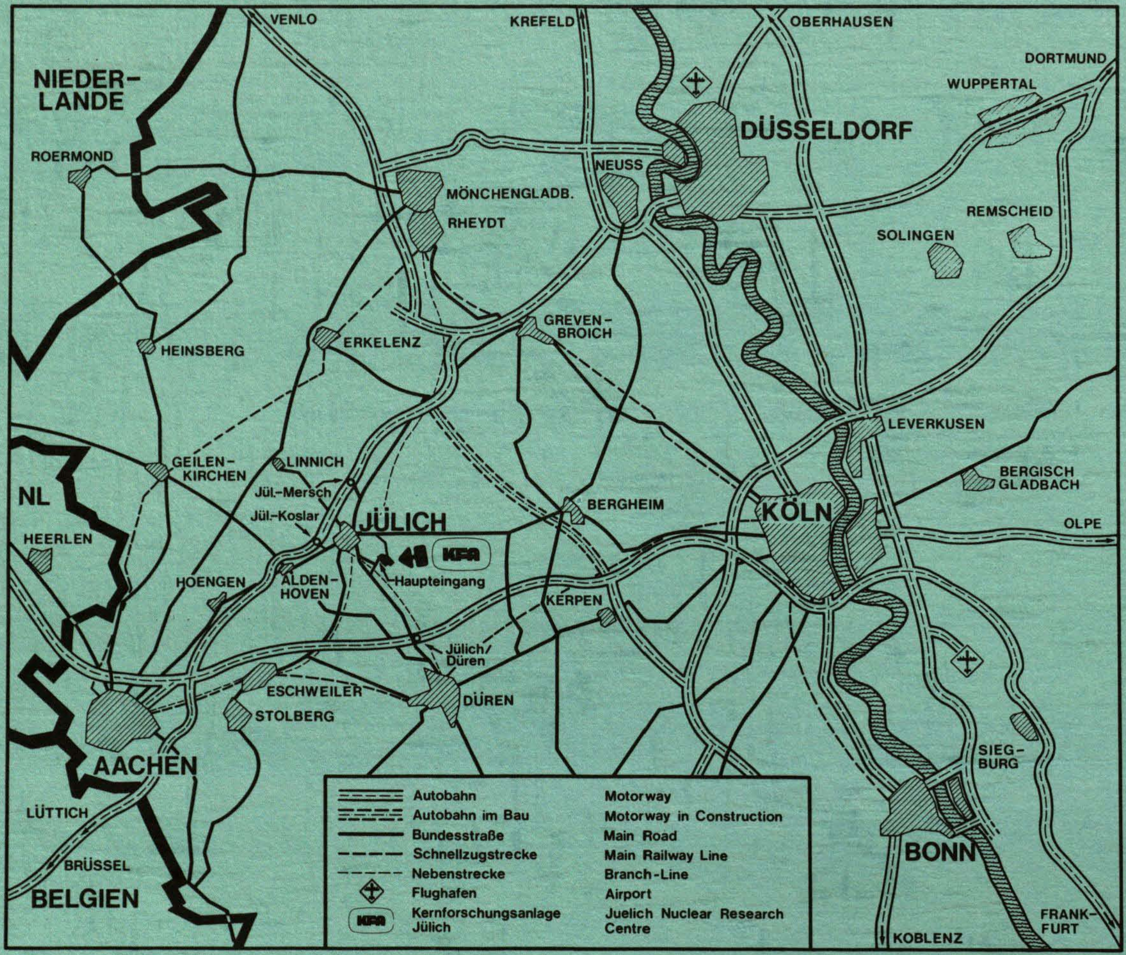
"OPTY"

A Universal Optical Model Code for the Elastic Scattering of Spinless Particles

by

H. Dabrowski, R. Planeta and A. Djaloeis

Jül - 1637
Januar 1980
ISSN 0366-0885



Als Manuskript gedruckt

Berichte der Kernforschungsanlage Jülich – Nr. 1637

Institut für Kernphysik Jül - 1637

Zu beziehen durch: ZENTRALBIBLIOTHEK der Kernforschungsanlage Jülich GmbH,
Jülich, Bundesrepublik Deutschland

"OPTY"

A Universal Optical Model Code for the Elastic Scattering of Spinless Particles

by

H. Dabrowski*, R. Planeta* and A. Djaloeis

*Institute of Nuclear Physics and Jagellonian University, Cracow, Poland

CONTENT

1. General description of the programme

The computer programme OPTY calculates the predictions of the Optical Model for the elastic scattering of spinless particles. Three types of parametrization (see below) are available for the real and the imaginary parts of the optical model potential (OMP). For a given option of the OMP the program automatically searches the optimum values of the potential parameters by minimizing the χ^2-value

$$\chi^2(a_1,..a_N) = \sum_i \left[\frac{\sigma_{exp}(\Theta_i) - \sigma_{th}(\Theta_i, a_1,..,a_N)}{\Delta\sigma_{exp}(\Theta_i)}\right]^2 \tag{1}$$

according to the GRADIENT[1] and/or the SIMPLEX[2,3] methods. At each angle Θ_i the quantities $\sigma_{exp}(\Theta_i)$, $\Delta\sigma_{exp}(\Theta_i)$ and $\sigma_{th}(\Theta_i)$ represent the experimental value, the estimated error and the theoretical value of the elastic scattering differential cross section, respectively. The OMP parameters are denoted by $a_1,...,a_N$.

The program allows four main options for the OMP:

A. Generalized[4] Woods-Saxon (GWS):

$$V_{opt}(r) = U*[f(r,r_U,a_U)]^{WYR} + i*W_V*[f(r,r_V,a_V)]^{WYI} - i*(4a_S W_S)*\frac{d}{dr}[f(r,r_S,a_S)]^{WYI} \equiv (WS)**WYR+i((WS)**WYI+WSD) \tag{2}$$

where

$$f(r,r_x,a_x) = \left[1+\exp\left(\frac{r-r_x*A^{1/3}}{a_x}\right)\right]^{-1} \tag{3}$$

The program optimizes the values of the parameters according to the search-configuration (see card-set VI of input data)

B. GWS + Fourier-Bessel (FB) Series[5]:

$$V_{opt}(r) = GWS(r) + \sum_{n=1}^{NBE} [WYSR*B_n+i*WYSI*C_n]*j_o\left(\frac{n\pi r}{R_{cut}}\right) \tag{4}$$

Here the parameters of the GWS should be kept fixed. The para meters WYSR and WYSI can take values 1.0 and 0.0, respectively. The programme optimizes the FB parameters according to the specified search-configuration (see card-set VI of input data).

C. GWS + Spline Function:

Here only two options are available

$$V_{opt} = \text{Real(GWS)} + i\, W_{spl}\,(S_1,\ldots,S_{NSPL}) \tag{5a}$$

$$\text{or:=}\quad V_{spl}(S_1,\ldots,S_{NSPL}) + i\,\text{Imag(GWS)} \tag{5b}$$

The programme optimizes the GWS and the spline parameters $S_1,\ldots,S_{NSPL}$ according to the specified search-configuration (see card-set VI of input data). The initial spline values $S_1,\ldots,S_{NSPL}$ can either be read in or computed in the program (see card-set IV).

D. Spline Function:

$$V_{opt} = V_{spl}\,(S_1,\ldots,S_{NSPU}) + i\,W_{spl}\,(SS_1,\ldots,SS_{NSPW}) \tag{6}$$

The initial spline values $S_1,\ldots,S_{NSPU}$ and $SS_1,\ldots,SS_{NSPW}$ are read in. The programme optimizes the spline parameters according the specified search-configuration (see card-set VI).

The spline function is given by[6]:

$$f(r) = \sum_{i=1}^{NSPL} (S_i\phi_i(r)+D_ih_i(r))$$

where

$$\phi_i(r) = \begin{cases} f(\frac{r-r_i}{r_{i+1}-r_i}) & \text{for } r_i \le r \le r_{i+1} \\ f(\frac{r-r_i}{r_{i-1}-r_i}) & \text{for } r_{i-1} \le r \le r_i \end{cases}$$

$$h_i(r) = \begin{cases} (r_{i+1}-r_i)g\,(\frac{r-r_i}{r_{i+1}-r_i}), & \text{for } r_i \le r \le r_{i+1} \\ (r_{i-1}-r_i)g\,(\frac{r-r_i}{r_{i-1}-r_i}), & \text{for } r_{i-1} \le r \le r_i \end{cases}$$

$f(x) = 2x^3-3x^2+1$ and $g(x) = x^3 - 2x^2 + x$. The coefficients D_i are computed in the programme.

The program is based on the programme GLOB[7] and is written in the FORTRAN-IV language and is available both in the CDC and IBM (double precision) versions.

As output the program gives

a. print-outs of:

(i) final values of the optical model parameters

(ii) the scattering matrix S_ℓ and the transmission coefficient T_ℓ

(iii) partial and total elastic and absorption cross sections

(iv) differential elastic scattering cross sections

b. a combined plot of the theoretical and experimental cross sections

2. Description of the main subroutines

Name	called by	Function
1. FORMF	FCN	Calculates the numerical values of the given potential according to KAST-option
2. FCN(CHISQ, X,IFLAG)	MAIN, SIMPLEX, GRADI	Solves the Schrödinger equation for each partial wave numerically. Matches the internal and asymptotic (Coulomb) wave functions at RMAX. Calculates $\sigma_{th}(\Theta_i)$ and χ^2.
3. COULOM (R, GAMMA, LMAX)	MAIN	Stored the Coulomb phase shifts as well as the values and the derivatives of the Coulomb (regular and irregular) function at RMAX
4. SIMPLEX		Minimizes χ^2-value by SIMPLEX method
5. GRADI		Minimizes χ^2-value by GRADIENT method

3. Input data

The input data consist of 8 card-sets:

I. Card-set (1 card)

Variable names : TITLE, TYPE

Format : (1x, 51A1, 24x, A4)

Variable meaning:

TITLE: title for the calculations

TYPE : method adopted for minimizing χ^2

Options:

TYPE = SIMP : SIMPLEX method

GRAD : GRADIENT method

ALSI : Combination of SIMPLEX and GRADIENT methods

II. Card-set (1 card)

Variable names : LLLLLL, IXX, MDD, LAB, IPI, MIKRO, MNDRUK, DX, LIT, LCM, NSPL, KAST

Format : (7I3, F3.0, 2I3, 42X, I3, I5)

Variable meaning:

LLLLLL : not used, leave blank

IXX : not used, leave blank

MDD : number of experimental cross sections $\sigma_{exp}(\Theta)$ (MDD $\leq$ 170)

LAB : choice of coordinate system

Options :

LAB = 0 : Θ, $\sigma_{exp}(\Theta)$ and $\Delta\sigma_{exp}(\Theta)$ are in lab. system

1 : Θ and $\sigma_{exp}(\Theta)$ and $\Delta\sigma_{exp}(\Theta)$ are in c.m.-system

IPI : Choice of presentation of errors

Options:

IPI = 0: percentage error ($\Delta\sigma_{exp}(\theta)/\sigma_{exp}$ in %)

1: absolute error ($\Delta\sigma_{exp}(\theta)$)

MIKRO : number of iterations for GRADIENT method ($\leq$ 999)

MNDRUK : number of iterations for SIMPLEX method ($\leq$ 999)

DX : preset limit for the difference in χ^2-values of two successive iterations. The program stops if $|\chi^2_{i+1} - \chi^2_i| \leq$ DX, i = iteration number. (suggested value $\approx$.01 or 0.0)

LIT : not used, leave blank

LCM : not used, leave blank

NSPL : number of splines (only if KAST = 3). See option C of card set IV for details (NSPL $\leq$ 17)

KAST : choice of optical model potential

Options:

KAST = 1: standard potential GWS with the form

= (WS) ** WYR + i(WS**WYI+WSD)

WS = Woods-Saxon, WSD = Woods-Saxon-Derivative.

(see option A of card-set IV)

2: Potential = GWS + Fourier Bessel (FB) Series

(see option B of card-set IV)

3: Potential has the form:

= (WS) ** WYR + i (spline Function)

or = (Spline Function) + i(WS**WYI+WSD)

(see option C of card-set IV)

4: Potential has the form:

= (Spline Function) + i (Spline Function)

III. Card-set (1 card)

Variable names : PARAM (I), I=1,10

Format : (10F8.0)

Variable meaning :

I=1 : AI - projectile mass (amu)

2 : ZI - projectile charge

3 : AT - target mass (amu)

4 : ZT - target charge

5 : E - Lab. incident energy (MeV)

6 : RC - reduced Coulomb radius

7 : RI - integration step in k·r unit (e.g. for $^{58}Ni+\alpha$ at E_α = 170 MeV, RI = 0.4; k = wave number)

Note: k.RMAX $\leq$ 250.

8 : not used, leave blank

9 : not used, leave blank

10 : not used, leave blank

IV. Card-set:

Four options for potential types are available:

option A for KAST = 1

B for KAST = 2

C for KAST = 3

D for KAST = 4

See "POTENTIAL OPTIONS" for details.

V. Card-set: (1 card)

Variable names: RMAX, DL, QMIN, QMAX, QDEL, YMAX, YMIN, NRZE, LEMON

Format : (7F10.0, 2I5)

Variable meaning:

LEMON = number of partial waves (LEMON ≤ 95)

If LEMON = 0, the default value

LEMON = integer (RHOMAX * k) + 2 is taken

RMAX = matching radius (in fermi)

DL = not used, leave blank

For plot routine : QMIN = Θ_{min}, minimum Θ for $\sigma_{th}(\Theta)/\sigma_R(\Theta)$

QMAX = Θ_{max}, maximum Θ for $\sigma_{th}(\Theta)/\sigma_R(\Theta)$

QDEL = $\Delta\Theta$ (≥ 0.2)

YMIN = lowest exponent for plot-decade — use only integrer values

YMAX = highest " " " " — use only integrer values

YMAX-YMIN = number of decades in the plot.

NRZE = number of bars per decade (needed to adjust plot-size)

NRZE ≤ 110/(YMAX-YMIN)

VI. Card-set: (1 card)

Variable : MIN (I), I=1, 36

Format : (36I1)

Options :

MIN(I) = 1 : ZPAR(I) optimized in search

0 : " kept fixed

ZPAR(I)	KAST = 1	KAST = 2	KAST = 3
I = 1	U	U	U
2	r_U	r_U	r_U
3	a_U	a_U	a_U
4	W_V	W_V	W_V
5	r_V	r_V	r_V
6	a_V	a_V	a_V
7	W_S	W_S	W_S
8	r_S	r_S	r_S
9	a_S	a_S	a_S
10	WYR	WYR	WYR
11	WYI	WYI	WYI

KAST = 1 : ZPAR(I), I $\geq$ 12 - not used

2 : ZPAR(12) - not used

(13) - not used

(14) - RCUT

ZPAR(14+K) = B(K), K=1, NBE

ZPAR(14+NBE+I) = C(I), I = 1, NBE

3 : ZPAR(12) - not used

(13) - not used

ZPAR(13+K) = S(K), K=1, NSPL

4 : ZPAR(I) = S(I), I=1, NSPU

ZPAR(NSPU+K)=S(NSPU+K), K=1, NSPW

Note: (NSPU+NSPW) $\leq$ 30

VII. Card-set (1 card)

Variable : XNORM (F10.0)

XNORM = overall normalization factor for the experimental data

VIII. Card-set (MDD cards, see card-set II)

Variables : TTT(I), DSIGD(I), ERR(I), I=1, MDD

Format : 3 F10.0

Variable meaning:

TTT(I) = Θ_i-value at which the i-th experimental cross section $\sigma_{exp}(\Theta_i)$ is given

DSIGD(I) = experimental value of $\sigma_{exp}(\Theta_i)$

ERR(I) = error of $\sigma_{exp}(\Theta_i)$ (see card-set II)

POTENTIAL OPTIONS:

Four options are available:

A. (KAST=1) : 5 cards (A1,...,A5), each with the format (3F10.0)

potential: GWS=(WS)**WYR+i(WS**WYI+WSD)

Card A1:	U,	r_U,	a_U
A2:	W_V,	r_V	a_V
A3:	W_S,	r_S,	a_S
A4:	WYR,	WYI	
A5:	leave blank		

B. (KAST=2) : 8 cards (B1,...,B8)

Potential has the form:

$$\mathrm{Pot}(r)=\mathrm{WS}(r)**\mathrm{WYR}+\mathrm{WYSR}*\left[\sum_{I=1}^{\mathrm{NBE}} B(I)*j_o\left(\frac{I*\pi*r}{\mathrm{RCUT}}\right)\right] +$$

$$i\left\{(\mathrm{WS}(r)**\mathrm{WYI}+\mathrm{WSD}(r))+\mathrm{WYSI}*\left[\sum_{I=1}^{\mathrm{NBE}} C(I)*j_o\left(\frac{I*\pi*r}{\mathrm{RCUT}}\right)\right]\right\}$$

Cards B1,...,B6: Format (6F10.0)

B1: U, r_U, a_U, W_V, r_V, a_V

B2: W_S, r_S, a_S, WYR, WYI, 0.0

B3: . . . B6: contain: 0.0, RCUT, B(1),...,B(NBE), C(1),...,C(NBE)

Card B7: WYSR, WYSI (2F10.0)

Options:

WYSR=1.0,WYSI=0.0	:	FB series added only to the real part
0.0, 1.0	:	" " " " " imaginary part
1.0, 1.0	:	" " " " to both real and imaginary parts
0.0, 0.0	:	equivalent to option KAST = 1

Card B8: NBE (I3), NBE $\leq$ 11

C. (KAST = 3) : 10 Cards (C1,...,C10)

Pot(r) = WS(r)**WYR + i [WS(r)**WYI+WSD(r)]+
WYSR*[VTAIL(r)†+VSPL[r,{S(I),XWSP(I)}, I=1, NSPL]]
WYSI*i [WTAIL(r)†+WSPL[r,{S(I),XWSP(I)}, I=1,NSPL]]

$\dagger$: defined only for r $\geq$ XWSP(NSPL)

Cards C1,...,C8 : Format (6F10.0)

Card C1 : U, r_U, a_U, W_V, r_V, a_V

C2 : W_S, r_S, a_S, WYR, WYI

C3, C4, C5 contains : 999., S(1),...,S(NSPL)

Card C6, C7, C8 contains : XWSP(1),...,XWSP(NSPL)

Card C9 : RVAT, AVT, RWAT, AWT, XXX, YYY (6F10.0)

Card C10: WYSR, WYSI (2F10.0)

Possible options:

	U	W_V	WYSR	WYSI	
a.	0.0	W_V	1.	0.	: Real part consists only of spline function VSPL calculated from the given values S(I)
b.	U	W_V	1.0	0.	: As in a), but VSPL calculated from the given potential shape parameters
c.	U	0.0	0.	1.	: As in a) but for the imaginary part
d.	U	W_V	0.	1.	: As in b) but for the imaginary part

Note: For the spline potential, the tail function is defined only for $r \geq$ XWSP(NSPL)

D. (KAST = 4) : 11 Cards (D1,...,D11)

Potential = VSPL[r,{S(I),XWSP(I)},I=1,NSPU] +VTAIL†(r)
+i*WSPL[r,{S(I),XWSP(I)}, I=NSPU+1,...,NSPU+NSPW]
+i*WTAIL†(r)

$\dagger$: real, defined only for $r \geq$ XWSP(NSPU)
imaginary, " " " $r \geq$ XWSP(NSPW)

Cards D1,...,D10: Format (6F10.0)

Card D1 ... D5 : contains S(1),...,S(NSPU+NSPW),...,S(30)

D6 ... D10 : contains XWSP(1),...,XWSP(NSPU+NSPW),...,XWSP(30)

D11: NSPU, NSPW (2I3)

D12: RVAT, AVT, RWAT, AWT, XXX, YYY (6F10.0)

Variables:

(i) Real part of the potential : (WS)**WYR

U = depth (MeV)

r_U = reduced radius (fm)

a_U = diffuseness (fm)

WYR = exponent of the potential form factor

(ii) Imaginary part of the potential: (WS**WYI+WSD)

a. Volume absorption

W_V = depth (MeV)

r_V = reduced radius (fm)

a_V = diffuseness (fm)

b. Surface absorption

W_S = depth (MeV)

r_S = reduced radius (fm)

a_S = diffuseness (fm)

WYI = exponent of the potential form factor

(iii) Fourier-Bessel (FB) Series

B(I)	:	FB-coefficients for the real potential
C(I)	:	" " " " imaginary potential
NBE	:	number of Fourier-Bessel components (considered)
WYSR	:	multiplicative factor for FB-coeff. (real pot.)
WYSI	:	" " " " (imag. pot.)

Notes:

1. Typical input values for B(I) and C(I) $\approx$ 0.001
2. Setting the value of any B(I) or C(I) to zero automatically excludes the corresponding FB-component from the search.

(iv) Spline function + Tail function

S(I)	:	given value of the spline function
XWSP(I)	:	radius at which S(I) is given (fm)
NSPL	:	number of splines required (KAST=3)
NSPU	:	" " " " for the real potential (KAST=4)
NSPW	:	" " " " for the imag.potential (KAST=4)
RVAT	:	reduced radius for the tail part of the real potential (fm)
AVT	:	diffuseness " " " " " " " " (fm)
XXX	:	exponent " " " " " " " "
RWAT	:	reduced radius for the tail part of the imag. pot.(fm)
AWT	:	diffuseness " " " " " " " " (fm)
YYY	:	exponent " " " " " " " "

Acknowledgement

One of the authors (H.D.) is grateful to Prof. Mayer-Böricke for making his (H.D.) stay in Jülich possible. Stimulating discussions with Prof. A. Budzanowski and Prof. K. Grotowski during the course of this work are gratefully acknowledged. The authors wish to thank Mrs. Dohmen for her patient typing of the manuscript.

```
//KPH020SP JOB (251,001100),DABROWSKI,TIME=(0,30)
/* JOBPARM L=3
/*ROUTE  PRINT KPH
//             EXEC GFCRT,NAME=KPH020AL
//G.SYSIN DD *
   NI 58   172.5 MEV                                                                GRAD
  1  2 72  0  0  0000                                                                  4
4.0026    2.        58.       28.       172.5     1.34      .4        15.       172.      2.
86.28     105.34    79.5      48.07     20.47     6.576
1.839     .5099     .04028    .006455   .4127     22.69
21.99     20.97     17.96     14.85     11.03     6.882
3.778     1.941     .9732     .2963     .1213     .05982
.002938   .0        .0        .0        .0        .0
.0        3.        4.        5.        6.        7.
8.        9.        11.       13.       .0        3.
4.        4.5       5.        5.5       6.        6.5
7.        7.5       8.        9.        10.       11.
13.       .0        .0        .0        .0        .0
1.38105   1.24952   1.56176   .63144     2.         1.
 10 15
15.       .0001     1.0       119.0     1.0       1.        -4.                 23   79
111111111111111111111111
1.00
4.4       28900.    7.
4.9       12500.    9.7
5.4       4270.     11.
5.9       2190.     3.5
6.4       2690.     3.5
6.9       3510.     2.5
7.4       3710.     2.5
7.9       3110.     3.1
8.4       2080.     5.1
8.9       1150.     7.4
9.4       426.      12.9
9.9       81.3      20.5
10.4      46.4      15.9
10.9      183.      9.7
11.4      347.      3.7
12.2      425.      2.5
12.7      399.      2.8
12.9      347.      4.
13.4      230.      5.1
13.9      117.      8.3
14.4      48.3      9.3
14.9      25.       6.
15.4      33.9      5.4
16.1      62.5      3.6
16.7      79.3      2.5
17.2      83.       2.5
17.7      76.1      2.5
18.2      57.4      3.4
18.7      41.6      3.8
19.2      26.7      4.6
20.2      18.6      4.
20.7      21.6      4.
21.2      26.4      2.5
21.7      28.7      2.5
22.2      29.       2.5
22.7      27.2      2.5
23.2      23.5      2.5
23.7      19.6      2.5
24.2      16.1      2.5
24.7      14.       2.5
25.2      13.1      2.5
25.7      12.7      2.5
26.2      13.1      2.5
26.7      13.3      2.5
27.2      13.1      2.5
27.7      12.6      2.5
28.2      11.       2.5
29.2      8.55      2.5
30.2      6.6       2.5
31.2      5.52      2.5
32.2      4.78      2.5
34.2      3.15      2.5
35.2      2.41      2.5
36.2      1.77      2.5
37.2      1.42      2.5
38.2      1.1       2.5
39.2      .864      2.5
40.2      .678      2.5
41.2      .487      2.5
41.7      .431      2.5
43.2      .271      2.6
44.7      .174      2.8
46.2      .114      3.3
47.7      .0722     4.4
49.2      .0399     5.8
50.7      .0282     6.6
53.2      .0126     7.3
56.2      .00517    10.6
59.2      .00208    12.1
62.2      .000909   18.
70.2      .0000779  50.
73.2      .0000378  70.
/*  END OF JOB
```

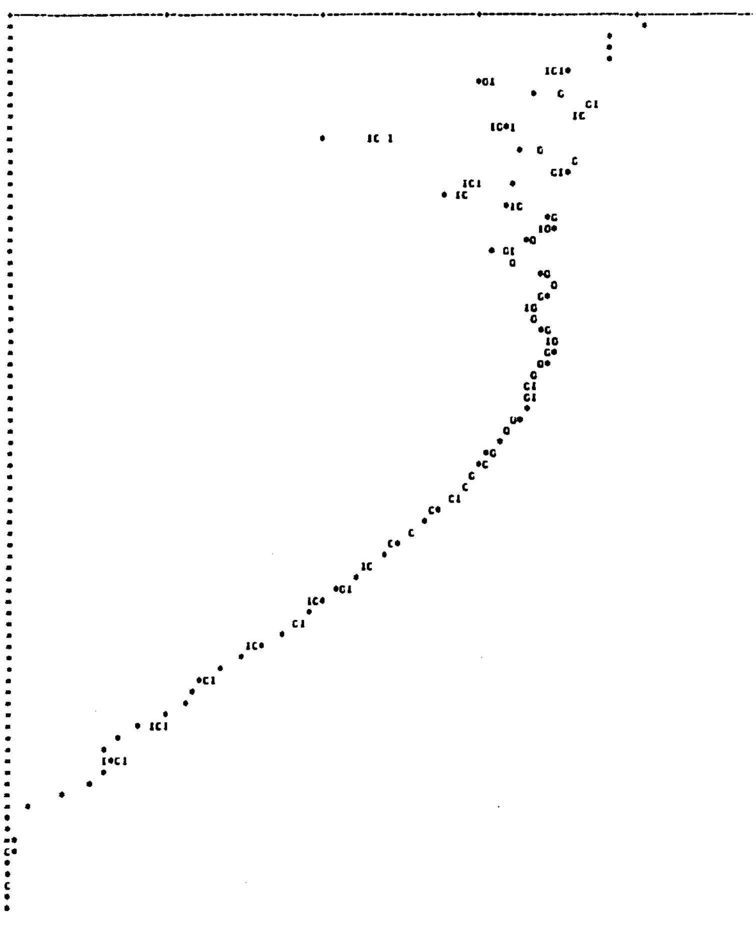
```
***** CMP-KRAKCW *****

KAST=1  TYPE OF PARAMETRIS. (S-W)**N

KAST=2                      FCURIER -BESSEL

KAST=3                      SPLINE U CR  W

KAST=4                      SPLINE L AND W

    TYPE CF PARAPETRISATICN            KAST=   4
PLTENT. R=  0.0  3.0  4.C  5.C  6.0  7.C  8.0  9.0 11.0 13.0
POTENT. W=  0.0  3.0  4.0  4.5  5.0  5.5  6.0  6.5  7.0  7.5  8.C  9.0 10.0 11.0 13.0

 NI 58   172.5 MEV                                                      GRAD

EXP. PCINTS NUMBER= 72      LAB= 0

***********************************************************************************************
*     AI =   4.00260   AT =  58.0CC00   ENERGY LIB=172.50   ENERGY CM=161.36   THETA MIN= 15.00   DT= 2.00 *
*     ZI =   2.00000   ZT =  28.00000   COEFICIENT CF NORMALISATION=  1.00     THETA MAX=172.00            *
***********************************************************************************************
*     K  =   5.37668   GAM=   1.34338   RHOMAX= 80.65C   RMAX (FM)= 15.000   LMAX= 79  RI=0.4000  STEP=.07 *
***********************************************************************************************


  STARTING PARAMETERS CF OPTICAL MCDEL


***********************************************************************************************
*      U =0.5347D+00        R1=0.6528C+00        A1=C.4927D+CC        WR=0.4000D-04              CHISC=     84.25    *
*      WV=0.2979D+00        R2=0.1269D+00        A2=0.4075D-01        WI=0.2558D-02      CHISC/POINT=     1.17     *
*      WS=0.1140D-01        R3=0.316CD-02        A3=0.2496C-03                                                     *
*      LC=0.1406D+00        DL=0.1363D+0C                                                                           *
*      RCUT=.12995D+00 B1=0.1113C+00 B2=0.9203D-01 B3=0.6835D-C1 B4=0.4265D-01 B5=0.2341D-01                        *
*      B6=0.1203D-01 B7=0.6031D-02 B8=0.1836D-02 B9=0.7517C-03 B10=0.3707D-03                                       *
*      B11=0.1821D-04 B12=C.0        B13=0.C        B14=0.C                     WYSR= 1.00  WYSI= 1.00              *
* B15=0.C        B16=0.0        B17=0.0        B18=0.0        B19=0.C        B20=0.0        B21=0.0                 *
*      B22=0.0                                                                                                      *
***********************************************************************************************


   KAST=  4 SPLINE PARAMETERS


   0.8628D+02   0.1053D+03   C.795CD+02   0.48C7C+02   0.2047D+02   0.6576D+01
   0.1839C+01   0.5099D+0C   0.4C28D-01   0.6455C-C2   C.4127D+0C   0.2269D+02
   C.2159D+02   0.2057D+02   0.1796D+02   0.1485C+02   0.11C30+C2   C.6882D+01
   0.3778D+01   0.1941D+C1   0.9732D+00   C.2963D+00   0.1213D+0C   0.5982D-01
   C.2538D-02   0.0          0.C          C.C          C.0          0.0


   RVAT= 5.3459  AVT= 1.2495  XXX= 2.C00
   RWAT= 6.0454  AWT= 0.6314  YYY= 1.000


       PARAMETERS CF OPTICAL MCDEL


***********************************************************************************************
*      U =0.5347D+00        R1=0.6528D+00        A1=C.4927C+0C        WR=C.4000D-04              CHISC=     84.25    *
*      WV=C.2979D+00        R2=0.1269D+00        A2=0.4075C-01        WI=0.2558D-02      CHISQ/POINT=     1.17     *
*      WS=0.1140D-01        R3=C.316CD-02        A3=0.2496C-03                                                     *
*      LC=0.1406D+00        DL=0.1363C+0C                                                                           *
*      RCUT=.12995D+00 B1=0.1113D+00 B2=0.9203C-01 B3=C.6835D-01 B4=0.4265D-01 B5=0.2341D-01                        *
*      B6=0.1203D-01 B7=0.6031D-02 B8=0.1836D-02 B9=0.7517C-03 B10=C.3707D-03                                       *
*      B11=0.1821D-04 B12=0.0        B13=0.C        B14=0.C                     WYSR= 1.00  WYSI= 1.00              *
* B15=0.C        B16=0.0        B17=0.0        B18=0.C        B19=0.0        B20=0.0        B21=0.0                 *
*      B22=0.0                                                                                                      *
***********************************************************************************************


   KAST=  4 SPLINE PARAMETERS


   0.8628D+02   0.1053D+03   0.795C0+02   C.48C7C+02   0.2047D+02   0.6576D+01
   0.1839D+01   0.5099D+00   0.4C28D-01   C.6455C-02   C.4127D+0C   0.2269D+02
   C.2159D+C2   0.2097D+02   0.1796D+02   0.1485C+02   C.1103C+02   0.6882D+01
   0.3778D+01   0.1941D+01   0.9732D+00   C.2963D+00   0.1213D+0C   0.5982D-01
   0.2938D-02   0.0          0.0          0.C          C.0          0.0


   RVAT= 5.3459  AVT= 1.2495  XXX= 2.000
   RWAT= 6.C454  AWT= C.6314  YYY= 1.000
```

N	THET.CM	EXP.CR.SEC.	EXP.ERRORS	EXP.CR./RUTH	ERR.RUTH.	TH.CR.SEC	TH.CR./RUTH	PARTIAL CHISQ %
1	4.70	C.253CD+05	0.1771D+04	0.4595D+C0	C.3216D-C1	C.2718D+05	0.4937D+C0	0.1341D+01
2	5.24	0.1094D+05	0.1062D+04	0.3C56D+C0	0.2964D-01	0.1C14D+05	0.2831D+00	0.6856D+00
3	5.77	0.3739D+04	0.4113D+03	0.1539D+C0	0.1693D-01	0.3084D+04	0.1270D+C0	0.3007D+01
4	6.31	0.1918D+04	0.6712D+02	0.1125D+C0	C.3937D-02	C.1584D+04	0.9289D-01	0.2939D+02
5	6.84	0.2356D+04	0.8246C+02	0.1912D+C0	0.6653D-C2	0.2267D+04	0.1840D+C0	0.1373D+01
6	7.38	0.3074D+C4	0.7686D+02	C.337CD+C0	0.8425D-C2	C.3115D+04	0.3415D+00	0.3334D+00
7	7.91	0.325CD+C4	0.8125D+02	0.4711D+C0	C.1178D-C1	0.3295D+C4	0.4776D+C0	0.3612D+00
8	8.44	0.2725D+04	0.8447D+02	0.5127D+C0	C.1589D-C1	0.2768D+04	C.5208D+00	C.3C59D+00
9	8.98	0.1823D+C4	0.9256D+02	C.4381C+C0	C.2235D-01	0.1868C+04	0.4490D+00	0.2790D+00
10	9.51	0.1008D+04	0.7459D+02	0.3051D+C0	C.2258D-C1	0.9775D+03	0.2959D+00	C.198C0+00
11	10.05	0.3734D+03	0.4817D+02	C.14C6D+C0	0.1814D-01	0.3483D+03	0.1311D+C0	0.3222D+00
12	10.58	0.7128D+02	0.1461D+02	G.33C0D-C1	C.6764D-C2	0.5423D+02	0.2510D-C1	0.1617D+01
13	11.11	0.4069D+02	0.6470D+01	0.2292D-C1	0.3645D-C2	C.3106D+02	0.1750D-C1	0.2630D+01
14	11.65	0.1605D+03	0.1557D+02	0.109C0+C0	0.1058D-01	0.1512D+03	0.1027D+00	0.4277D+00
15	12.18	0.3044D+C3	0.1126D+02	0.2472D+C0	0.9147D-02	C.2912D+03	0.2365D+00	0.1638D+01
16	13.04	0.3730D+C3	0.9326D+01	0.3968D+C0	C.9915D-C2	C.38C7D+03	0.4049D+00	0.8031D+00
17	13.57	0.3503D+C3	0.9808D+01	0.4371D+C0	0.1224D-C1	0.3348D+03	0.4178D+C0	0.2949D+01
18	13.70	0.3047D+C3	0.1219D+02	0.4046D+C0	0.1618D-01	0.3016D+03	0.4005D+00	0.7426D-01
19	14.32	0.2020D+03	0.1030D+02	0.3120D+C0	C.1591D-C1	C.2036D+03	0.3145D+00	0.2811D-01
20	14.85	0.1028D+03	0.8531D+01	C.1836D+C0	C.1524D-C1	0.1124D+03	0.2007D+00	0.1494D+01
21	15.38	0.4244D+02	0.3947D+01	0.8726D-C1	0.8115D-02	0.5094D+02	0.1047D+00	0.5502D+01
22	15.92	0.2197D+02	0.1318D+01	0.5173D-C1	C.31C4D-C2	0.2547D+02	0.5995D-01	0.8322D+01
23	16.45	C.2981D+C2	0.1610D+01	0.7999D-C1	0.4319D-C2	0.2853D+02	0.7657D-01	0.7448D+00
24	17.20	0.5498D+02	0.1979D+C1	0.1760D+C0	0.6335D-02	0.5381D+02	0.1722D+00	0.4125D+00
25	17.84	0.6578D+C2	0.1745D+01	C.2582D+C0	0.6455D-02	0.7086D+02	0.2622D+00	C.4504D+00
26	18.37	0.7306D+02	0.1827D+01	0.3038D+00	C.7596D-C2	0.7298D+02	0.3035D+C0	0.2478D-02
27	18.90	0.6701D+02	0.1675D+01	0.3121D+C0	C.78C4D-02	0.6440D+02	0.3000D+00	0.2881D+01
28	19.44	0.5056D+02	0.1719C+01	C.263CD+C0	C.8940D-C2	C.4961D+02	0.2580D+00	0.3674D+00
29	19.97	0.3666D+C2	0.1393D+01	0.2122D+C0	0.8063D-02	0.3422D+02	0.1981D+C0	0.3630D+01
30	2C.5C	0.2354D+02	0.1083C+C1	0.1512D+C0	0.6955D-02	0.2268D+02	0.1457D+C0	0.7398D+00
31	21.57	0.1641D+C2	0.6564D+00	0.1288D+CC	C.5152D-02	C.1667D+02	0.1308D+C0	0.1851D+00
32	22.10	0.1906D+02	0.7626D+00	0.1648D+C0	C.6591D-C2	0.1964D+02	0.1698D+00	0.6864D+00
33	22.63	0.2331D+02	0.5828D+00	C.2213D+CC	C.5533D-C2	C.2337D+02	0.2219D+00	C.1097D-01
34	23.16	0.2535D+C2	0.6338D+00	0.2638D+CC	C.6596D-C2	C.2582D+02	0.2687D+C0	0.6426D+00
35	23.69	0.2563D+02	0.6407D+00	0.2917D+00	C.7292D-C2	C.2603D+02	0.2962D+00	0.4624D+00
36	24.23	0.24C5D+C2	0.6012D+00	0.2987D+C0	C.7468D-C2	C.2408D+02	0.2992D+00	0.3875D-02
37	24.76	0.2079D+C2	0.5197D+C0	0.2813D+C0	C.7032D-02	C.2079C+02	0.2813D+00	0.5405D-06
38	25.29	0.1735D+02	0.4336D+00	0.2552D+C0	C.6379D-02	0.1719D+02	0.2529D+C0	0.1549D+00
39	25.82	0.1425D+C2	0.3564D+00	C.2276D+00	0.5690D-C2	C.1418D+02	0.2263D+00	0.5841D-01
40	26.35	0.1240D+C2	0.3100D+C0	0.2145C+C0	0.5363D-02	0.1224D+02	0.2116D+C0	C.3413D+00
41	26.88	0.1161D+C2	0.2902D+00	0.2172D+C0	C.5430D-02	C.1141D+C2	0.2135D+00	0.5574D+00
42	27.41	0.1126D+C2	0.2815D+0C	0.2275C+C0	C.5687D-C2	C.1141D+02	0.2304D+C0	0.3111D+00
43	27.95	0.1162D+02	0.29C5D+00	0.2531D+C0	0.6328D-C2	C.1175D+02	0.2560D+00	0.2467D+00
44	28.48	0.1181D+02	0.2551C+00	0.2768D+C0	0.6920D-C2	C.1201D+02	0.2816D+C0	C.5628D+00
45	29.01	0.1163D+02	0.29C8D+00	0.2932D+C0	0.7331D-02	0.1186D+02	0.2990D+00	0.7472D+00
46	29.54	0.1120D+02	0.2795D+C0	C.3029D+C0	C.7573D-C2	0.1122D+02	0.3036D+C0	0.1012D-01
47	30.07	0.9779D+01	0.2445D+C0	0.2837D+C0	C.7092D-02	0.1016D+02	0.2948D+C0	0.2937D+01
48	31.13	0.7610D+01	0.1962D+00	0.2527D+C0	C.6318D-C2	C.763CD+01	0.2534D+00	0.1317D-01
49	32.19	0.5881D+01	0.1470D+C0	0.2225D+C0	C.5564D-C2	0.5745D+01	0.2174D+C0	0.1013D+01
50	33.25	0.4925D+01	0.1231D+00	0.2114D+C0	0.5284D-02	0.4824D+01	0.2070D+00	0.7997D+00
51	34.31	0.4270D+C1	0.1067D+0C	0.2C70D+C0	0.5175D-C2	C.4256D+01	0.2063D+00	0.1839D-01
52	36.42	0.2821D+C1	0.7052D-C1	C.1724D+C0	C.4310D-C2	0.2766D+01	C.1691D+00	0.7069D+00
53	37.48	0.2161D+01	0.5403C-01	0.1475D+C0	C.3688D-C2	0.2C87D+01	0.1425D+00	0.2213D+01
54	38.54	0.1589D+C1	0.3973D-01	C.12C7D+C0	0.3018D-02	0.1610D+01	0.1223D+C0	0.3182D+00
55	39.59	0.1277D+01	0.3152D-C1	C.1C76D+C0	C.2690D-C2	C.1282D+01	0.1080D+C0	0.2577D-01
56	40.65	0.9905D+0C	0.2476D-C1	0.9236D-C1	0.23C8D-02	0.1025C+01	0.9555D-01	0.2303D+01
57	41.70	0.7792D+00	0.1948D-C1	C.8011D-C1	C.2CC3D-02	0.8012D+00	0.8237D-01	0.1517D+01
58	42.75	C.6124D+00	0.1521D-01	C.6925C-C1	0.1731D-02	0.6072D+00	0.6866D-01	0.1364D+00
59	43.81	0.4405D+00	0.1101D-01	C.5465D-01	0.1366D-02	0.4505D+00	C.5589D-C1	0.9779D+00
60	44.33	0.3902D+00	0.9754D-02	C.5065D-C1	C.1266D-02	0.3865D+00	0.5018D-01	0.1634D+00
61	45.91	0.2459C+00	0.6394D-02	0.3644D-C1	C.9475D-C3	C.2431D+00	0.3603D-C1	0.2245D+00
62	47.48	0.1583D+C0	0.4432D-C2	0.2664D-C1	C.7460D-03	0.1569D+00	0.2641D-01	0.1139D+00
63	49.C6	0.1040D+0C	0.3431D-02	0.1978D-C1	C.6528D-C3	C.1C37D+0C	0.1973D-C1	0.5797D-02
64	50.63	0.66C1D-01	0.29C5D-02	C.1413D-C1	C.6219D-03	0.6376D-01	0.1365D-C1	0.7161D+00
65	52.19	0.3658D-C1	0.2121D-02	0.8775D-C2	0.5089D-03	C.3860D-01	0.9261D-02	0.1082D+01
66	53.76	C.2592D-01	0.1711D-02	0.6940D-C2	C.458CD-C3	C.2587D-01	0.6925D-02	0.1213D-02
67	56.37	0.1164D-01	0.8494D-03	0.37C9C-C2	0.27C8D-C3	0.1156D-01	0.3686D-C2	C.8770D-02
68	59.49	0.4802D-02	0.5050D-03	C.1864D-02	0.1976D-03	0.4132D-02	0.1604D-C2	0.2055D+01
69	62.60	0.1944D-C2	0.2352D-C3	C.9070D-C3	C.1C57D-03	0.1655D-02	0.7723D-C3	0.1788D+01
70	65.70	0.8547D-03	0.1538D-C3	0.4741D-C3	C.8533D-C4	0.7732D-03	0.4289D-C3	0.3329D+00
71	73.92	0.7453D-04	0.3727D-04	C.6241D-C4	C.3121D-C4	0.1332D-03	0.1116D-C3	0.2943D+01
72	76.99	0.3441D-04	0.2549D-C4	0.35C1D-C4	C.2451D-C4	0.4921D-04	0.4732D-04	0.2991D+00

L	RES	IPS	TC	ETA L	ARG ETA L	SIG ABSL	SIG EL L
0	0.0332538397175	-0.0438674400721	0.996970	0.055047	-52.835980	1.003	1.018
1	-0.0505065929196	-0.0204388027656	0.997031	0.054485	22.032080	3.251	3.599
2	-0.0382024579322	0.0373287496811	0.997141	0.053469	-44.277364	5.418	5.865
3	0.0013593647525	0.0315957334862	0.997295	0.052013	88.502445	7.587	7.607
4	0.0313490619244	0.0391842311713	0.997482	0.050181	51.330715	9.756	9.192
5	0.0451300992189	0.0165671079939	0.997689	0.048075	20.158024	11.926	10.903
6	0.0452878753571	-0.0061322963160	0.997911	0.045701	-7.711352	14.098	12.877
7	0.0360641326824	-0.0239050340610	0.998126	0.043267	-33.538335	16.270	15.156
8	0.0212729342204	-0.0347134427755	0.998342	0.040713	-58.499410	18.444	17.719
9	0.0045454637832	-0.0380190038527	0.998534	0.038290	-83.182255	20.618	20.490
10	-0.0111910801674	-0.0341221606612	0.998710	0.035910	71.842034	22.792	23.362
11	-0.0233907181947	-0.0243513855089	0.998840	0.033766	46.154767	24.966	26.193
12	-0.0299084640234	-0.0106062867315	0.998988	0.031809	19.477619	27.141	28.825
13	-0.0297880950829	0.0044519623415	0.999093	0.030119	-8.500194	29.315	31.116
14	-0.0226380606313	0.0176486787098	0.999176	0.028705	-37.940066	31.489	32.968
15	-0.0098532474675	0.0257118405973	0.999242	0.027535	-69.032279	33.663	34.378
16	0.0055549039805	0.0261490166947	0.999285	0.026733	78.006823	35.836	35.489
17	0.0189483641444	0.0175998990846	0.999317	0.026135	43.529591	38.010	36.620
18	0.0256191381836	0.0025310503972	0.999335	0.025784	6.526756	40.182	38.176
19	0.0221258824717	-0.0137541283224	0.999321	0.026052	-31.860365	42.354	40.536
20	0.0081701545188	-0.0248727163444	0.999315	0.026180	-71.815782	44.525	43.858
21	-0.0111519721010	-0.0242422842537	0.999288	0.026684	65.296576	46.696	47.805
22	-0.0262599053837	-0.0101387198096	0.999208	0.028149	21.111166	48.864	51.510
23	-0.0273398343537	0.0116927565696	0.999116	0.029735	-23.155535	51.031	53.914
24	-0.0109762685108	0.0289768025743	0.999040	0.030986	-69.253587	53.199	54.470
25	0.0155012048415	0.0287728277437	0.998932	0.032683	61.686696	55.364	53.764
26	0.0358863456670	0.0062302161141	0.998673	0.036423	9.848937	57.520	53.539
27	0.0324803052537	-0.0289163049895	0.998109	0.043487	-41.677791	59.657	56.001
28	-0.0018357151617	-0.0531634441435	0.997170	0.053195	88.022614	61.768	62.366
29	-0.0540554216870	-0.0405250224442	0.995435	0.067562	36.861401	63.824	71.342
30	-0.0951620569941	0.0203268947614	0.990531	0.097309	-12.057353	65.663	79.535
31	-0.0564243370327	0.1184754262288	0.976664	0.152755	-50.858693	66.867	83.265
32	-0.0439151798761	0.2283868046238	0.945911	0.232571	-79.115798	66.817	80.662
33	0.0579328130573	0.3230900274258	0.892257	0.328243	79.834432	64.966	72.220
34	0.1916971624954	0.3849068711903	0.815407	0.429643	63.501323	61.143	60.077
35	0.3356685753470	0.4075865251097	0.721200	0.528015	50.526797	55.646	46.871
36	0.4717501847728	0.3979012396078	0.619126	0.617190	40.146224	49.116	34.697
37	0.5893493349399	0.3660274534301	0.518691	0.693764	31.843208	42.276	24.664
38	0.6847617766540	0.3224731020333	0.426983	0.756979	25.230737	35.729	17.028
39	0.7589192672200	0.2740011047908	0.347865	0.807549	19.985145	29.865	11.530
40	0.8150502710374	0.2311182600042	0.282277	0.847185	15.831390	24.848	7.713
41	0.8569150460029	0.1907432903492	0.228314	0.877887	12.549055	20.684	5.128
42	0.8879958030369	0.1558494634104	0.187174	0.901568	9.954431	17.290	3.402
43	0.9111556417178	0.1264056444059	0.153817	0.919882	7.898298	14.543	2.257
44	0.9285458811100	0.1020100720465	0.127396	0.934132	6.269376	12.322	1.500
45	0.9417470084357	0.0820315375971	0.106383	0.945313	4.978226	10.521	1.001
46	0.9519114975057	0.0657613331518	0.089540	0.954180	3.951913	9.049	0.671
47	0.9598452493338	0.0526247346594	0.075928	0.961287	3.138173	7.839	0.452
48	0.9661115144280	0.0421024649983	0.064856	0.967028	2.495332	6.837	0.308
49	0.9711297464013	0.0336667678845	0.055774	0.971713	1.985514	6.000	0.212
50	0.9752170136959	0.0269174353907	0.048227	0.975588	1.581048	5.293	0.147
51	0.9786039045582	0.0215770789618	0.041869	0.978842	1.263101	4.687	0.103
52	0.9814598262991	0.0173544542003	0.036435	0.981613	1.013015	4.158	0.074
53	0.9839158768976	0.0139734863797	0.031714	0.984015	0.813655	3.688	0.053
54	0.9860727155334	0.0112730375698	0.027534	0.986137	0.654992	3.261	0.038
55	0.9880016415256	0.0091543534856	0.023769	0.988044	0.530860	2.867	0.027
56	0.9897471591823	0.0074873517510	0.020345	0.989775	0.433430	2.498	0.020
57	0.9913323377794	0.0061392597749	0.017223	0.991351	0.354825	2.152	0.014
58	0.9927675130255	0.0050390815262	0.014387	0.992780	0.290819	1.829	0.010
59	0.9940594109705	0.0041590280044	0.011829	0.994068	0.239718	1.530	0.007
60	0.9952135226614	0.0034628079977	0.009537	0.995220	0.199358	1.254	0.005
61	0.9962320359174	0.0029026584059	0.007513	0.996236	0.166939	1.004	0.003
62	0.9971075818550	0.0024442647636	0.005770	0.997111	0.140452	0.784	0.002
63	0.9978330587696	0.0020679144752	0.004325	0.997835	0.118740	0.597	0.001
64	0.9984091146196	0.0017517825844	0.003176	0.998411	0.100530	0.445	0.001
65	0.9988489098062	0.0014699858044	0.002299	0.998850	0.084321	0.327	0.000
66	0.9991746016579	0.0012067847863	0.001649	0.999175	0.069201	0.238	0.000
67	0.9994105009917	0.0009442513157	0.001178	0.999411	0.055280	0.173	0.000
68	0.9995783255680	0.0007537097391	0.000843	0.999579	0.043203	0.125	0.000
69	0.9996959850197	0.0005822748430	0.000608	0.999696	0.033372	0.092	0.000
70	0.9997780858176	0.0004474752228	0.000444	0.999778	0.025644	0.068	0.000
71	0.9998362760105	0.0003410636212	0.000327	0.999836	0.019545	0.051	0.000
72	0.9998790961535	0.0002551327515	0.000242	0.999879	0.014620	0.038	0.000
73	0.9999119670451	0.0001850952082	0.000176	0.999912	0.010606	0.028	0.000
74	0.9999377601729	0.0001291045154	0.000124	0.999938	0.007398	0.020	0.000
75	0.9999577885087	0.0000861950490	0.000084	0.999958	0.004939	0.014	0.000
76	0.9999727562658	0.0000550136602	0.000054	0.999973	0.003152	0.009	0.000
77	0.9999833398349	0.0000335743090	0.000033	0.999983	0.001924	0.006	0.000
78	0.9999903640620	0.0000195999555	0.000019	0.999990	0.001123	0.003	0.000
79	0.9999947294552	0.0000109424302	0.000011	0.999995	0.000627	0.002	0.000

ELS= 1514.338   ACS= 1681.910   TCS= 3196.248

TMIN= 1.00   TMAX= 119.00   TDELTA= 1.00   YMAX= 1.0   YMIN=-4.0   LZMAX=23



References:

1) M.A. Melkanoff, D.S. Saxon, J.S. Nodvik and D.G. Cantor, "A Fortran Program for Elastic Scattering Analysis with Nuclear Optical Model", University of California Press, Berkeley, USA, 1961.

2) J.A. Nelder and R. Mead, Comp. Journal 7 (1965) 308.

3) F. James, M. Roos, Comp. Phys. Comm. 10 (1975) 843.

4) A. Budzanowski, H. Dabrowski, L. Freindl, K. Grotowski, S. Micek, R. Planeta, A. Strzalkowski, M. Bosman, P. Leleux, P. Macq, J.P. Meulders and C. Pirart, Phys. Rev. C17 (1978) 951.

5) E. Friedman and C.J. Batty, Phys. Rev. C17 (1978) 34.

6) J. Borysowicz and J. Hetherington, Phys. Rev. C7 (1973) 2293.

7) H. Dabrowski, R. Planeta, Report No. 947, INP, 1976, Cracow, Poland