Appendix A

EMPIRE optional input keywords

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The optional input allows modifications to the default model parameters. Optional input consists of an arbitrary number of records, entered in any order and closed with the GO record, which indicates the end of the input. In the simplest case (all defaults), only the GO record must be entered.

Each optional record starts with an alphanumeric keyword **NAME**. If the first character of the line (i.e. **NAME(1:1)**) is *, # or !, then this line contains comments and is ignored by the code. There might be an arbitrary number of comments line in the optional input. If the first character of the line **NAME(1:1)** is @, then this line contains a title, which will be printed in EMPIRE outputs; obviously the title is not used in any calculations. Multiple titles are allowed. Users are strongly encouraged to use titles and comments in EMPIRE inputs; that will be a significant step toward a better documentation of our theoretical calculations and evaluations.

The optional-input keyword **NAME** is followed by the value VAL and four positional parameters I1, I2, I3, I4. The keyword indicates a physical quantity, such as the binding energy or level density parameter or scaling parameter. VAL takes the numerical value of the given quantity or scaling parameter.
The positional parameters are typically used to specify to which nucleus the quantity should be applied (generally if these are omitted the value is applied to all nuclei in the given calculation). Positional parameters may be also used to indicate the estimated uncertainty of the quantity defined by the input keyword (except optical model parameters for which the uncertainty is defined by VAL). Each record must be in the FORTRAN format:

FORMAT (A6,G10.5,4I5) **NAME**,VAL,I1,I2,I3,I4

Fixed format allows to avoid typing zeros if no input is needed for some positional parameters.

The GO record indicates end of the optional input and starts calculations. It may be followed by an unlimited list of incident energies (and titles or comments) (one per record) terminated with a record containing a negative value. Anything below this line will be ignored by the code.

Calculation control

NEX Maximum number of energy steps in the integration set to VAL (default: min(50, NDEX)). NDEX parameter is defined in the *dimension.h* file.

ENDF Controls output for ENDF formatting and exclusive/inclusive emission

= 0 no ENDF formatting (default).

> 0 output for the full ENDF formatting will be created (including double differential MF=6) as shown in the two examples below

= 2 means all reactions emitting 2 or less particles are exclusive

the rest are inclusive (lumped into MT=5)

= 3 means all reactions emitting 3 or less particles are exclusive

the rest are inclusive (lumped into MT=5)

RECOIL Controls calculation of recoils,

= 0 recoils are not calculated (default if ENDF = 0, no ENDF formatting)

= 1 recoils are calculated (default if ENDF > 0, ENDF formatting)

If keyword ENDF=0 is given in the input, then recoils are not calculated independently of the keyword RECOIL.

PRGAMM Controls calculation of primary gammas

= 0 Primary gammas are not printed (default)

> 1 Primary gammas are printed

If keyword ENDF=0 is given in the input, then primary gammas are not printed independently of the keyword PRGAMM.

GAMPRN Controls printing of gamma production cross sections (n,xng)

= 0 Gamma production cross sections are not printed (default)

> 0 Gamma production cross sections files and plots are produced.

HRTW Controls HRTW calculations (width fluctuation correction)

= 0 no HRTW

> 0 HRTW width fluctuation correction up to the energy set by VAL.

FISSPE Controls calculation of prompt fission neutron spectra (PFNS).

= 0 PFNS are not calculated (default)

= 1 PFNS are calculated using Los Alamos model [**?**]

= 2 PFNS are calculated using Kornilov parameterization [**?**]

CNANGD Controls calculation of CN angular distribution.

= 0 Compound nucleus (CN) angular distribution assumed isotropic (default)

> 0 Compound nucleus (CN) angular distribution assumed anisotropic; collective levels must be present and DIRECT > 0.

INTERF Controls calculation of interference effects between direct and compound decay.

= 0 Compound nucleus (CN) and direct cross section are added incoherently (default)

= 1 Compound nucleus (CN) and direct interference considered by Engelbrecht-Weidenmuller transformation (see Phys.Rev. C8(1973)859-862). Collective levels must be present and DIRECT > 0.

FISSPE Controls calculation of prompt fission neutron spectra (PFNS).

= 0 PFNS are not calculated (default)

= 1 PFNS are calculated using Los Alamos model [**?**]

= 2 PFNS are calculated using Kornilov parameterization [**?**]

BENCHM Controls if benchmark calculation is requested.

= 0 no benchmark calculation (default),

> 0 benchmark calculation requested. Energies do not need to be in increasing order.

KALMAN Controls calculation of a sensitivity matrix,

= 0 no sensitivity matrix calculations (default),

= 1 sensitivity matrix is calculated.

RANDOM Controls randomization of input parameters that were input with uncertainty

= 0 no random sampling is allowed (default)

> 0 random sampling based on normal (Gaussian) distribution with the given 1-sigma parameter uncertainty

< 0 random sampling based on uniform distribution with the given 1-sigma parameter uncertainty

ISOMER The minimum isomer half life (in seconds) set to VAL

This keyword defines minimum half-life of the state to be considered an isomer (default 1. = 1 second)

Output control

IOUT Main output control set to VAL

= 1 input data and essential results (all cross sections) (default),

= 2 as IOUT=1 plus fusion spin distribution, yrast state population, γ-transition parameters, fusion barrier, inclusive spectra,

= 3 as IOUT=2 + γ and particle spectra + discrete levels' decay + double differential cross sections (if MSD>0),

= 4 as IOUT=2 + ORION output + residual nuclei continuum population (up to spin 12),

= 5 as IOUT=2 + ORION output + transmission coefficients (up to l=12),

= 6 as IOUT=2 + ORION output + level densities (up to spin 12). Should be used to get ZVV level density plots.

NOUT MSC calculation output control set to VAL (default: 0).

EDDFIG (default 0). If VAL> 0, then emission spectra (DE) and double differential cross sections (DD) will be plotted at incident energy E=VAL for emitted particle I3 (default 1= neutrons); double differential will be plotted at angles I1 and I2.
Emitted particles could be neutrons (I3=1 - default, I3=2 -protons, I3=3 -alphas, I3=4 -deuterons. Angular values I1 and I2 are expected in degrees and should be less than 175 deg. Default angles are 30 and 150 degrees.

Optical Model Potential

OMPOT Selects optical model parameters for outgoing particle

The value of I1 selects the outgoing particle as follows: =1 neutrons, =2 protons, =3 alphas, =4 deuterons, =5 tritons, =6 He-3; VAL must be set to a RIPL catalog number (e.g. 2408 for Capote et al OMP) of the potential as it appears in the empire/RIPL/optical/om-data/om-index.txt file or in Help => 'RIPL omp' when using GUI. For backward compatibility this number can be entered with a negative sign.

DIRPOT Optical model parameters to be used in DWBA or coupled-channels calculations by ECIS/OPTMAN codes. Parameters are the same as above, except that I1 need not be specified (always refers to the incident channel).

RELKIN Override the RIPL defined kinematics used in a given optical model potential,

= 0 classical (default),

= 1 relativistic.

TRGLEV Excited level of the target is set to VAL (e.g., VAL=3 for the 2^{nd} excited state; default: 1 (ground state)).

UOMPab Uncertainty of the parameters defining the potential strength of the optical model potential. The letter a can be V (real potential strength) or W (imaginary potential strength). The letter b can be V (volume) or S(surface). Thus the combinations VV (real volume), WV (imaginary volume), and WS (imaginary surface) specify 3 different terms in the RIPL optical potential described in Refs. [**?**, **?**]. The combination VS is not allowed, as parameters of the real surface potential (VS) are usually not used in deriving phenomenological potentials. The exception is for dispersive potentials, but in this case the VS uncertainty is fully determined by the uncertainty of the imaginary surface potential (WS). The uncertainty of the spin-orbit potential is also not considered as its influence on calculated cross sections is small.
The relative uncertainty in % of the corresponding parameter (defined by letters *a* and *b*) is given by VAL, target's Z and A numbers are defined by I1 and I2, respectively. I3 defines the outgoing particle, i.e., the incident particle for the inverse reaction (I3=1 for neutron, I3=2 for protons, etc). Some examples of potential strength uncertainties are given below.

```
* The three lines below define 1.5% uncertainty of the real
* volume potential strength and 10% uncertainty of the real
* and imaginary surface potential strength for neutron and
* proton emission channels from the 56-Mn compound nucleus
UOMPVV   1.50000  25    55   1
UOMPWV  10.0000   25    55   1
UOMPWS  10.0000   25    55   1
* The same for the proton emission channel
UOMPVV   1.50000  24    55   2
UOMPWV   2.5000   24    55   2
UOMPWS  10.0000   24    55   2
```

UOMPcd Defines the uncertainty of the geometry component of the optical model potential. The letter c can be R (radius) or A (diffuseness). The letter d

can be V (real volume), W (imaginary volume) or S (imaginary surface). Thus the following six combinations are possible: RV and AV (real volume radius and diffuseness), RW and AW (imaginary volume radius and diffuseness), and RS and AS (surface radius and diffuseness).
The relative uncertainty of the corresponding parameter (defined by letters c and d) is given by VAL (in percent), target's Z and A are defined by I1 and I2, respectively. I3 defines the outgoing particle, i.e. the incident particle for the inverse reaction (I3=1 for neutron, I3=2 for protons, etc). It is recommended to avoid variations of potential strength (e.g. VV,WV) and corresponding potential radius (e.g. RV, RW) in the same run, as those parameters are strongly correlated within the optical model.
Some examples of geometry uncertainties of the optical model parameters are given below.

```
* The two lines below define 1.5% uncertainty of the
* imaginary volume radius, and 2.5% uncertainty of the
* imaginary volume diffuseness for a neutrons incident
* on 55Mn nucleus
UOMPRW   1.50000  25    55   1
UOMPAW   2.5000   25    55   1
* The same for the proton emission channel
* corresponding to the surface potential.
UOMPRS   1.50000  24    55   2
UOMPAS   2.5000   24    55   2
```

Scattering on collective levels

EMPIRE includes two coupled-channels codes: ECIS and OPTMAN[**?**, **?**, **?**]. ECIS is the default optical model solver, but OPTMAN should be used for selected potentials, when soft-rotor couplings are desired, as well as for actinide potentials that couple levels beyond the ground state rotational band.

DIRECT Controls use of coupled-channel calculations (ECIS and OPTMAN)

- **=0** spherical OM used (default)
- **=1** Coupled Channel (CC) method used for calculation of inelastic scattering to collective levels in the incident channel. If a selected OM potential is of CC type, the elastic and reaction cross sections are also taken from ECIS/OPTMAN calculations. Otherwise, spherical OM results are used. Transmission coefficients for all outgoing channels are calculated with spherical OM.

=2 as above but transmission coefficients for the inelastic outgoing channels are calculated within Coupled Channel approach (longer calculation time).

=3 as DIRECT=1 but DWBA is used instead of CC for calculation of inelastic scattering to collective levels in the incident channel. All transmission coefficients calculated with spherical OM.

NOTE: OM potential to be used by ECIS/OPTMAN might be different from the one used in the rest of the calculations and can be specified with the DIRPOT option.

CALCTL Controls use of calculated transmission coefficients for both projectile and ejectiles.

= 0 Transmission coefficients calculated during the first run are stored, and reused in subsequent EMPIRE runs (default),

> 0 Transmission coefficients are calculated for each run even if they were calculated before and respective files exist. This option is useful to calculate some quantities that are only used if TL are not already present (e.g. Bass fusion barrier in HI induced reactions).

NOTE: this option slows down the execution of the code in subsequent runs by up to a factor of 10 (additional time is needed to calculate TLs again; reading them is much faster).

EcDWBA Automatically selects all discrete levels to be used in DWBA calculations for uncoupled collective levels.
The default cut-off energy is $3 * 30/A^{2/3}$, and the default maximum spin 4. With these defaults all levels ($J < 5$) with excitation energy less than 2.4 MeV for ^{238}U), and less than 6.2 MeV for ^{56}Fe are considered.
The default selection rules could be modified by the VAL parameter that redefines the cut-off energy, and the parameter I1 that sets the maximum spin.

RESOLF Energy resolution in MeV used to spread calculated collective cross sections in the continuum set to VAL.
This parameter is used if there are collective levels (in the *-lev.col file) that are located in the continuum (see the *cont* flag). The scattering cross sections on these levels will be calculated by DWBA (if keyword DIRECT > 0).

DEFNUC Deformation of the target nucleus set to VAL.
The threshold value to assume that the nucleus is deformed is 0.1 If you

want to force the assumption of sphericity for a given nucleus you can use this parameter with a value less than 0.1 this parameter also affects the deformation used in MSD calculations.

ECONT The energy continuum for the nucleus with Z=I1 and A=I2 starts at energy given by VAL in MeV.
This parameter overwrites the continuum cut-off energy defined in the default RIPL levels for a given nucleus (or even the value given in the local LEVELS file). If not nucleus is given, then the value is ignored.

Scaling parameters correcting for model deficiencies

These parameters are non-physical parameters designed to be used in nuclear data evaluation to correct for reaction model deficiencies, and to define model parameters' uncertainties. They are also used for covariance calculations by providing a straightforward way to calculate sensitivities (required as input for KALMAN), and to allow for random sampling of model parameters within defined uncertainties (required for Monte Carlo generation of theoretical model covariances).

TUNE The equilibrium decay width Γ_i^{EQ} of the ejectile i given by I3, for the nucleus with Z=I1 and A=I2 will be multiplied by VAL.
Estimated relative uncertainty in % of this parameter can be given by I4.

TUNEFI The fission decay width Γ_F will be multiplied by VAL for the nucleus with Z=I1 and A=I2.
Estimated uncertainty of this parameter can be given by I3.

TUNEPE The preequilibrium decay width Γ_i of the ejectile i given by I1 will be multiplied by VAL. It applies only to the PE decay from the compound nucleus calculated by PCROSS (exciton model), input keyword PCROSS > 0.
Estimated relative uncertainty in % of this parameter can be given by I2.

PFNNIU Used in prompt fission neutron (PFN) calculations. The evaluated total prompt neutron multiplicity $\widetilde{\nu}$ (read from NUBAR-EVAL.ENDF) will be multiplied by VAL (default: 1.). The relative uncertainty of the scaling factor in % could be given by I1.

PFNTKE Used in prompt fission neutron (PFN) calculations. The total kinetic energy (TKE) of the fission fragments will be multiplied by VAL (default: 1.). The TKE enters the energy balance equation defining the total excitation energy of the fissioning system $U_{exc} = E_{rel} - TKE + E_{incid} + B_n$. This parameter could be interpreted as the uncertainty of the measured

fission kinetic energy.
The relative uncertainty of the scaling factor in % could be given by I1.

PFNALP Used in prompt fission neutron (PFN) calculations. The default parameter α ($\alpha_0 = 1$ for Madland-Nix (LA) model [**?**] and α_0 0.9 for Kornilov parameterization [**?**]) will be multiplied by VAL (default: 1.). The values E_f^L and E_f^H of the average kinetic energy per nucleon of the average light fragment AL and average heavy fragment AH are scaled by α. The effect of this parameter on PFNS calculations is strongly correlated with TKE (see keyword PFNTKE above). // Physically, this parameter allows for a reduction of the kinetic energy of the fragment due to neutron emission during Coulomb acceleration.
The relative uncertainty of the scaling factor in % could be given by I1.

PFNRAT Used in prompt fission neutron (PFN) calculations. The default parameter $r = T_f^L/T_f^H$ ($r_0 = 1$ for Madland-Nix (LA) model [**?**] and $r_0 = 1.248$ for Kornilov parameterization [**?**]) will be multiplied by VAL (default: 1.). This parameter defines the ratio of temperatures of the light to heavy fragment. Experimental evidence strongly supports 20% higher temperature of the light fragment.
The relative uncertainty of the scaling factor in % could be given by I1.

PFNERE Used in prompt fission neutron (PFN) calculations. The total fission energy release (E_{rel}) will be multiplied by VAL (default: 1.). The E_{rel} enters the energy balance equation defining the total excitation energy of the fissioning system $U_{exc} = E_{rel} - TKE + E_{incid} + B_n$. The relative uncertainty of the scaling factor in % could be given by I1.

TMAXW Used in prompt fission neutron (PFN) calculations. PFNS plots are scaled by a Maxwellian function with T = VAL (default: 1.32) MeV.

DEFSTA The static deformation needed in rigid-rotor CC calculations will be multiplied by VAL (default: 1.).
The relative uncertainty of the scaling factor in % could be given by I1.
It is recommended not to vary dynamical deformation above 10 MeV (i.e. set its uncertainty to zero) to avoid numerical instabilities.

DEFDYN Dynamical deformations of uncoupled levels for DWBA calculations will be multiplied by VAL (default: 1.).
Dynamical deformations are listed for all collective levels in the collective file (*-col.lev).
The relative uncertainty of the scaling factor in % could be given by I1.

It is recommended not to vary dynamical deformation above 10 MeV (i.e. set its uncertainty to zero) to avoid numerical instabilities.

ELARED The shape elastic cross section will be multiplied by VAL (default: 1.).
The change is also reflected in the total cross section.
The relative uncertainty of the scaling factor in % could be given by I1.

FUSRED The fusion (reaction) cross section will be multiplied by VAL (default: 1.).
The change is also reflected in the total cross section.
The relative uncertainty of the scaling factor in % could be given by I1.

FCCRED The calculated direct cross section for discrete collective levels will be multiplied by VAL (default: 1.). Cross sections of both coupled and uncoupled discrete levels are scaled.
The uncertainty of the scaling factor in % could be given by I1.
It has no effect if DIRECT keyword is set to zero in the input (default).

FCORED The DWBA calculated direct cross section for collective levels in the continuum will be multiplied by VAL (default: 1.). Giant multipole resonances are also scaled if specified in the collective level file (flagged with negative deformation).
The uncertainty of the scaling factor in % could be given by I1.
It has no effect if DIRECT keyword is set to zero in the input (default).
A value of zero could be used to supress DWBA collective levels in the continuum, without recalculating the transmission coefficients (TLs).

TOTRED The total cross section will be multiplied by VAL (default: 1.).
The relative uncertainty of the scaling factor in % can be given by I1.
TOTRED is applied through other scaling factors, namely ELARED,FUSRED,FCCRED and FCORED.
If those factors are present, then the final scaling will be a product of them (e.g., if both TOTRED and FUSRED are specified, then the fusion (reaction) cross section will be multiplied by FUSRED*TOTRED.
This parameter is recommended to be used to correct small deficiencies (3%) of your optical model calculated total cross sections. It is not recommended to be used for simulation of the experimental fluctuations of total cross section.

CELRED The compound elastic cross section will be multiplied by VAL (default: 1.).
The relative uncertainty of the scaling factor in % can be given by I1.
This parameter may be used to simulate the CN resonances (obviously not included in the optical model), or to simulate physical effects arising from

the compound-direct processes interference (Engelbrecht-Weidenmuller transformation). The interference increases the compound inelastic cross sections, reducing others compound channels (incl. the compound elastic). If you use CELRED and CINRED at the same energy please note that some interference will result as they affect the same quantities.

CINRED The compound inelastic cross section to discrete levels will be multiplied by VAL (default: 1.).
The discrete level number can be given by I1.
The relative uncertainty of the scaling factor in % can be given by I2.
This parameter may be used to simulate physical effects arising from the compound-direct processes interference (Engelbrecht-Weidenmuller transformation). The interference increases the compound inelastic cross sections, reducing others compound channels (incl. the compound elastic).

DXSRED The calculated deuteron pick-up/stripping cross section for incident deuteron on the target nucleus will be multiplied by VAL). It has no effect on other incident particles.

> 0 deuteron pick-up/stripping parameterization of Kalbach used for incident deuterons (default: 1.),

$= 0$ deuteron pick-up/stripping suppressed.

Optical model fitting

FITOMP Controls fitting of optical model potential in the incident channel,

=0 No fit (default)

=1 GUI assisted manual fitting; independently of what is specified in the input only total, elastic, capture and inelastic scattering are calculated. If plots with 'List names' ompR1 and eventually ompR2 are set they will be updated and reproduced after each run.

=2 Automatic fit. See default EMPIRE input (../scripts/skel.inp) or the description of the parameter FITabc below for keywords to be placed in the input.

FITabc Selects an optical model parameter for adjustment. The letter a can be R (real) or I (imaginary) and the letter b can be V (volume), S (surface) or O (spin-orbit). Thus the combinations RV, IV, RS, IS, RO and IO specify the 6 different terms in the RIPL optical potential described in Refs. [**?**, **?**]. The letter c can be V (potential strength), R (radius) or D (diffuseness). The initial shift in the parameter is given by VAL and

the maximum allowed variation is given by 0.01*I1. I2 specifies which of the parameters in the potential strength, radius or diffuseness is to be adjusted.
Some examples are given below.

```
FITRVV     0.     500    1    !fit real volume depth (+- 5 MeV)
FITIVV     0.     100    1    !fit imag. volume depth (+- 1 MeV)
FITISV     0.     100    1    !fit imag. surface depth (+- 1 MeV)
FITRVR     0.      10    1    !fit real volume radius (+- 0.1 fm)
FITIVR     0.      10    1    !fit imag. volume radius (+- 0.1 fm)
FITRVD     0.      10    1    !fit real volume diffus. (+- 0.1 fm)
FITISD     0.       5    1    !fit imag. surf. diffus. (+- 0.05 fm)
```

FITDEF Selects the deformation parameter of multipole I2 for adjustment. The initial shift in the parameter is given by VAL and the maximum allowed variation is given by 0.01*I1. The value of I2 can be 2 or 4 for rotational nuclei and 2 or 3 for vibrational nuclei, e.g.,

```
FITDEF     0.      10    2    !fit l=2 (quadrupol) defor. (+- 0.1)
```

FITWT Multiplies weights of experimental data of type MF=I1 and MT=I2 in χ^2 by VAL.

FITWT0 Multiplies weights of natural element experimental data in χ^2 by VAL.

FITITR Sets the number of iterations in the gradient χ^2 minimization to VAL=maxitr+0.01*itmax,
where maxitr is the number of times the gradient is calculated and itmax is the number of iterations along each gradient (default is 3.05).

FITEMX Maximum incident energy of experimental data used in fitting set to VAL (default is 30 MeV).

FITGRD Defines the initial grid of incident energies of nuclear model calculations used to obtain χ^2. When set, the first interval is VAL, the second VAL +0.001*I1, the third VAL+0.002*I1, etc. (The default incident energy grid is the one given in the input file.)

Fusion

These input parameters are typically used for heavy ion induced reactions.

CSREAD Controls HI fusion cross section determination,

> 0 HI fusion cross section is set to VAL [in mb],

= -1 distributed barrier model used ,

= -2 simplified coupled-channel treatment CCFUS-code (default for HI).

Note: CSREAD has no effect if *.fus* file (*FUSION* in manual mode) exists.

BFUS Fusion barrier height in the distributed barrier model (Eq. **??**) set to VAL (default: B_{fus} calculated by CCFUS).

SIG SIGMA in the distributed barrier model (Eq. **??**) set to VAL (default: $0.05B_{fus}$).

TRUNC Truncation in the distributed barrier model (Eq. **??**) set to VAL (default: 2.).

EXPUSH Extra-push energy set to VAL (default: 0.).

CRL Critical l-value for HI fusion (Eq. **??**) set to VAL (default: 0).

DFUS Diffuseness in the transmission coefficients for HI fusion (Eq. **??**) set to VAL (default: 1.).

Photo-absorption

E1 = 0 E1 photo-absorption blocked

= 1 E1 photo-absorption selected

M1 = 0 M1 photo-absorption blocked

= 1 M1 photo-absorption selected

E2 = 0 E2 photo-absorption blocked

= 1 E2 photo-absorption selected

QD Quasideuteron photo-absorption cross section normalized by a factor VAL

CCFUS input

CCFUS code provides a simplified coupled-channel treatment to obtain the reaction cross section in near-barrier heavy ion reactions. It is not recommended for reactions with light incident particles ($A < 5$).

DV DV barrier parameter in CCFUS set to VAL. This parameter can be used to adjust the fusion barrier. Typical range for changes $-10 < DV < 10$. (default: 10).

FCC FCC parameter in CCFUS set to VAL

- **=0** diagonalization of the coupling is performed at the barrier position r_b,
- **=1** exponential character of the form factor is taken into account. A second order estimation of the position and height of the effective barriers is carried out within a one-Fermi distance from r_b. This option is recommended for strong coupling (default).

NSCC Number of inelastic surface channels in CCFUS set to VAL (default: 4).

NACC Number of additional channels set to VAL (default: 0).

BETCC Deformation of the I2th collective mode set to VAL.

FLAM Multi-polarity of the I2-th collective mode set to VAL (entered with positive sign for target modes and negative sign for projectile modes) (default: 2, 3, -2, -3, needs NSCC numbers).

QCC Q-value of the I2th collective channel set to VAL - excitation energy of the collective level adopted with a negative sign (default: - energies of the first 2+ and 3- levels in the target and the projectile).

FCD Strength of the coupling at the barrier for I2th collective mode set to VAL. For FCC=1 the characteristic radial dependence of the one-particle transfer form factor is assumed. Used only if NACC> 0 (no default).

Multi-step Direct

MSD Controls Multi-step Direct calculations,

- **= 0** no MSD calculations (default),
- **= 1** MSD calculations selected - ORION + TRISTAN will be executed,
- **= 2** MSD calculations selected including the MSD contribution to discrete levels. This option should be used with care if coupled channel optical model potentials are employed. Since MSD gives the vibration component of the direct cross section it sometimes it might be summed with the rotational CC contribution but summing it with the vibrational CC one would be an obvious double-counting.

MSDMIN The minimum energy to start MSD calculations set to VAL (default: 5.).

DEFMSD Deformation β_2 of the Nilsson Hamiltonian set to VAL (default: 0.).
The Nilsson hamiltonian is used to obtain single-particle levels employed in MSD calculations.

WIDEX Experimental energy resolution set to VAL (default: 0.2).

GAPP Proton pairing gap for target set to VAL (default: $12/\sqrt{A}$).

GRANGP Energy window around the E_F^p for proton pairing calculations for target set to VAL (default: 5.).

GAPN Neutron pairing gap for target set to VAL (default: $12/\sqrt{A}$).

GRANGN Energy window around the E_F^n for neutron pairing calculations for target set to VAL (default: 5.).

HOMEGA $\hbar\omega$ oscillator energy (default: $41.47/\mathrm{A}^{1/3}$ MeV).

EFIT Coupling constants of multi-polarity I1 fitted to the level at energy VAL (defaults: -1 for $\lambda = 0$, E_{GDR} for $\lambda = 1$, energies of the first low-lying 2+, 3-, and 4+ levels for $\lambda = 2$, 3, 4, respectively).

RESNOR Response function for multi-polarity I1 will be normalized by factor VAL (default: 1).

ALS spin-orbit coupling strength in the harmonic oscillator (default: 1.5).

Multi-step Compound

MSC Controls Multi-step Compound calculations,

= 0 no MSC calculations (default),

= 1 MSC calculations selected.

XNI Initial exciton number set to VAL (default set internally depending on the case, 3 for nucleon induced reactions).

GDIV Single particle level densities in preequilibrium models (MSC, DTRANS, PCROSS) set to A/VAL (default: 13.0).

TORY Ratio of unlike to like nucleon-nucleon interaction cross section set to VAL. Used for the determination of the relative share between neutron and protons in the exciton configurations (default: 4.).

EX1 Initial number of excitons that are neutrons set to VAL (default set internally depending on the case and on TORY).

EX2 Initial number of excitons that are protons set to VAL (default set internally depending on the case and on TORY).

D1FRA Ratio of the spreading GDR width to the total GDR width set to VAL (default: 0.8).

GST Controls γ-emission in MSC,

= 0 no γ-emission in MSC (default),

= 1 γ-emission in MSC selected.

STMRO =0 closed form p-h state densities selected (default)

Monte Carlo pre-equilibrium model (HMS)

HMS Controls Monte Carlo pre-equilibrium calculations,

= 0 HMS disabled (default),

= 1 HMS enabled.

NHMS Number of events in HMS set to VAL

CHMS Default damp rate in HMS multiplied by VAL

FHMS Transition densities used in HMS set by VAL

= 0 Exciton densities are used,

= 1 Fermi gas densities are used,

= 2 Exact NR Fermi gas densities are used,

= 3 Exact rel. Fermi gas densities are used.

PCROSS exciton model with Iwamoto-Harada cluster emission (PCROSS)

PCROSS Controls calculations with PCROSS:

= 0 PCROSS disabled (default)

> 0 PCROSS enabled with mean free path multiplier set to VAL. VAL must be greater than 0.5 and lower than 3. Estimated relative uncertainty in % of this parameter can be given by I1.

PEDISC Controls how discrete levels are treated in PCROSS:

= 0 Preequilibrium contribution to discrete levels neglected (default).

> 0 Preequilibrium contribution to discrete levels considered.

PESPIN Controls how preequilibrium spin cut-off paramater is calculated in the exciton model (PCROSS):

= 0 Exciton model spin cut-off parameter taken as 2*0.26*A^(2/3) (default). This is equivalent to the assumption that spin-distribution is equal to the spin-distribution of the n=2 (p=h=1) exciton states independent of the emission energy and of the exciton number n.

> 0 Exciton model spin cut-off parameter taken as (p+h)*0.26*A^(2/3) (default).
This produces higher-spin states at lower emission energies, changing the spin-distribution of the pre-equlibrium emission.

If MSD model is active, then PESPIN is reset to the default value of zero.

PEPAIR Controls how pairing is treated in PCROSS.

> 0 Pairing corrections included in PCROSS calculations (default).

= 0 Pairing corrections not considered in PCROSS calculations.

GTILNO Single particle level density parameter g (in PCROSS) multiplied by VAL for the nucleus with Z=I1 and A=I2.
Estimated relative uncertainty in % of this parameter can be given by I3.

MAXHOL Coefficient defining the equilibrium exciton number (in PCROSS) given by VAL. VAL must be greater than 0.1 and lower than 1.5 (Default coefficient 0.54). If the coefficient is bigger than 0.54 means that the preequilibrium contribution is bigger, as contribution from higher exciton states will be considered. Coefficient lower than 0.54 will produce smaller preequilibrium contribution.

Selection of Level density model

LEVDEN Selects level density approach,

= 0 EMPIRE-specific level densities, adjusted to RIPL-3 experimental D_{obs} and to discrete levels (default),

= 1 Generalized Superfluid Model (GSM, Ignatyuk et al), adjusted to RIPL experimental D_{obs} and to discrete levels,

= 2 Gilbert-Cameron level densities (parametrized by Ijinov et al), , adjusted to RIPL experimental D_{obs} and to discrete levels,

= 3 RIPL-3 microscopic HFB level densities.

FITLEV Option for adjusting range of discrete levels used in the calculations. Plots of cumulative number of discrete levels along with the integrated level densities are created and calculations stop at this point.

> 0 cumulative plots of discrete levels will be displayed. If LEVDEN=0 the energy range of the plot will extend VAL MeV above the last discrete level,

= 0 no cumulative plots (default).

LDSHIF Excitation energy shift in the BCS region set to VAL for the nucleus with Z=I1 and A=I2 (default 1.).
The input value is being reduced by 1, allowing for positive or negative energy shift. The default value of 1 means that the resulting energy shift is zero.
This parameter is applicable for GSM type of LD models (LEVDEN < 2).

ATILNO Value of the level density parameter $\widetilde{a}$ will be multiplied by VAL for the nucleus with Z=I1 and A=I2. Estimated relative uncertainty in % of this parameter can be given by I3.
This parameter is applicable if keyword LEVDEN < 3 (i.e. for all level density models but HFB).

Gilbert and Cameron level density model

GCROA Level density parameter a in Gilbert-Cameron approach

> 0 parameter a in nucleus Z=I1, A=I2 set to VAL ,

= 0 parameter a in all nuclei according to Ignatyuk systematics,

= -1 parameter a in all nuclei according to Arthur systematics,

= -2 parameter a in all nuclei according to Ilijnov systematics (default).

GCROUX Level density parameter U_x in Gilbert-Cameron approach for nucleus Z=I1, A=I2 set to VAL (default calculated internally).

GCROD Pairing shift Δ in Gilbert-Cameron approach for nucleus Z=I1, A=I2 set to VAL (default determined internally according to Gilbert-Cameron table, for $Z > 98$ and/or $N > 150$ $\Delta = 12/\sqrt{A}$ is taken).

GCROE0 Level density parameter E_0 in Gilbert-Cameron approach for nucleus Z=I1, A=I2 set to VAL (default calculated internally).

GCROT Level density parameter T in Gilbert-Cameron approach for nucleus Z=I1, A=I2 set to VAL (default calculated internally).

RIPL-3 HFB level density model

ROHFBP HFB pairing-like parameter to shift in energy numerical HFB level densities for nucleus Z=I1, A=I2 set to VAL. Default is taken from the internal file (*empire/RIPL/densities/total/level-densities-hfb/zxxx.cor*) estimated in RIPL-3. This value is overwritten by ROHFBP thus the change in the calculations is with respect to to the zero-shift case rather than to the default calculations.
Estimated uncertainty of this parameter can be given by I3.

ROHFBA HFB pseudo a parameter to adjust numerical HFB level densities for nucleus Z=I1, A=I2 set to VAL. Tabulated HFB level densities are multiplied by the factor $exp(ROHFBA)\sqrt(U))$, which is proportional to the dominant energy dependence of the Fermi gas level densities. Positive values of ROHFBA increase level densities while negative decrease them.
The default value is taken from the RIPL-3 file (*empire/RIPL/densities/total/level-densities-hfb/zxxx.cor*). ROHFBA overwrites the default thus the change in the calculations is with respect to the no-adjusted case rather than to the default calculations that use default adjustment if available in the *zxxx.cor* file.
Estimated uncertainty of this parameter can be given by I3.

Fission

FISSHI Controls treatment of the fission channel for nucleus Z=I1, A=I2

- **= 0** advanced low-energy fission treatment with multi-humped barriers. Recommended for light particle or photon induced fission (default).
- **= 1** high energy fission over single-humped barrier with dynamical effects. Recommended for heavy ion reactions when fission channel is important.
- **= 2** fission ignored.

The following options are valid only when FISSHI = 0

FISBAR Controls origin of fission barrier data for nucleus Z=I1,A=I2

= 0 internal EMPIRE fission barrier library (/data/EMPIRE-fisbar)

= 1 RIPL-3 empirical fission barriers (/RIPL/fission/empirical-barriers.dat) (default)

= 2 Parabolic approximation derived from numerical RIPL-3 HFB barriers (/RIPL/fission/HFB-parab-fisbar.dat)

= 3 One-dimensional non-parabolic numerical RIPL-3 HFB barriers (/RIPL/fission/HFB2007/z0xx.dat, $79 < xx < 99$)

FISDEN Controls level densities at saddle points for nucleus Z=I1, A=I2

= 0 EGSM (low K limit)

= 3 HFB microscopic calculations

FISOPT Controls subbarrier effects for nucleus Z=I1, A=I2

= 0 no subbarrier effects

= 1 subbarrier effects considered

= 2 subbarrier effects considered including isomeric fission and gamma emission inside the wells (under development)

= 3 the same as 2; but the phases are calculated assuming the barrier (or well) is represented by uncoupled parabola (under development)

FISDIS Controls discrete transitional states

= 0 no discrete states above fission barrier for nucleus Z=I1, A=I2

= 1 discrete states above fission barrier for nucleus Z=I1, A=I2

FISMOD Controls multi-modality of fission for nucleus Z=I1, A=I2

= 0 single-modal fission

= 1 multimodal fission (2 modes)

= 2 multimodal fission (3 modes)

FISATn The fission level-density parameter $\widetilde{a}_F$ at the saddle point n will be multiplied by VAL for the nucleus with Z=I1 and A=I2 (default 1.).
The letter n take values 1,2,3 according to the barrier number. Estimated uncertainty of the level density parameter at saddle n can be given by I3.

FISVEn The vibrational enhancement parameter of fission level-density at the saddle point n will be multiplied by VAL for the nucleus with Z=I1 and A=I2 (default 1.).
The letter n take values 1,2,3 according to the barrier number. Estimated uncertainty of the vibrational enhancement parameter at saddle n can be given by I3.

FISDLn The fission level density at the saddle point n will be shifted by VAL for the nucleus with Z=I1 and A=I2 (default 1.).
The letter n take values 1,2,3 according to the barrier number. Estimated uncertainty of the fission pairing parameter DEL at saddle n can be given by I3.

FISVFn The height of the fission barrier n will be multiplied by VAL for the nucleus with Z=I1 and A=I2 (default 1.).
The letter n take values 1,2,3 according to the barrier number. Estimated uncertainty of the barrier height can be given by I3.

FISHOn The width of the fission barrier n will be multiplied by VAL for the nucleus with Z=I1 and A=I2 (default 1.).
The letter n take values 1,2,3 according to the barrier number. Estimated uncertainty of the barrier width can be given by I3.

FISTGA Gamma transition probability for the isomeric gamma cascade in the second well.

The following options are valid only when FISSHI = 1

QFIS Liquid drop fission barriers multiplied by VAL (default: 1).

BETAV Viscosity parameter in Eqs. **??**, **??** and **??** set to VAL ($10^{-21}s^{-1}$) (default: 4).

SHRJ Shell correction to fission barrier damped (Eq. **??**)to 1/2 at spin VAL (default: 24).

SHRD Diffuseness of the shell correction damping (Eq. **??**) set to VAL (default: 2.5).

TEMP0 Temperature at which shell correction fade-out (Eq. **??**) space starts set to VAL (default: 1.65).

SHRT Parameter in the temperature shell correction fade-out (Eq. **??**) set to VAL (default: 1.066).

DEFGA d (amplitude) in the Gaussian term of Eq. **??** set to VAL (default: 0. - no correction).

DEFGW ΔJ_G (width) in the Gaussian term of Eq. **??** set to VAL (default: 10).

DEFGP J_G (position) in the Gaussian term of Eq. **??** set to VAL (default: 40).

Gamma-ray strength functions

GSTRFN Controls modeling of the γ-ray strength function

= 0 EGLO enhanced generalized Lorentzian (Uhl-Kopecki) as in 2.18 and earlier

= 1 MLO1 modified Lorentzian version 1 (Plujko, RIPL) (default)

= 2 MLO2 modified Lorentzian version 2 (Plujko, RIPL)

= 3 MLO3 modified Lorentzian version 3 (Plujko, RIPL)

= 4 EGLO enhanced generalized Lorentzian (RIPL)

= 5 GFL (Mughabghab)

= 6 SLO standard Lorentzian

WEDNOR Weisskopf single particle estimates for E1 γ transitions will be multiplied by VAL for the nucleus with Z=I1 and A=I2 (ATTENTION default: 0.01). In the table of GDR parameters in *.lst file this quantity is referred to as CE1.

WEQNOR Weisskopf single particle estimates for E2 γ transitions will be multiplied by VAL for the nucleus with Z=I1 and A=I2 (ATTENTION default: 0.1). In the table of GDR parameters in *.lst file this quantity is referred to as CE2.

WEMNOR Weisskopf single particle estimates for M1 γ transitions will be multiplied by VAL for the nucleus with Z=I1 and A=I2 (ATTENTION default: 0.1). In the table of GDR parameters in *.lst file this quantity is referred to as CM1.

GDR parameters

GDRGFL Selects source of GDR parameters

= 0 Messina systematics

= 1 experimental or systematics of RIPL (default)

GDRDYN Controls GDR treatment,

= 0 GDR shape depends on the ground state deformation (default),

= 1 GDR shape dependence accounts for the rotation induced deformation (spin dependent, Eq. **??**).

EGDR1 GDR energy of first peak set to VAL (default calculated internally from systematics).

GGDR1 GDR width of first peak set to VAL (default calculated internally from systematics).

CSGDR1 GDR cross section of first peak set to VAL (default calculated internally from systematics).

EGDR2 GDR energy of second peak set to VAL (default calculated internally from systematics).

GGDR2 GDR width of second peak set to VAL (default calculated internally from systematics).

CSGDR2 GDR cross section of second peak set to VAL (default calculated internally from systematics).

GDRWP Factor c in the energy increase of the GDR width (Eq. **??**) set to VAL (default: 0.0026).

GDRWA1 GDR width of first peak increased by VAL (default: 0).

GDRWA2 GDR width of second peak increased by VAL (default: 0).

GDRESH GDR position shifted by VAL (default: 0).

GDRSPL Splitting of GDR peaks increased by VAL (default: 0).

GDRST1 GDR cross section of first peak multiplied by VAL (default: 1).

GDRST2 GDR cross section of second peak multiplied by VAL (default: 1).

MAXMUL Maximum multipolarity of gamma rays set to VAL (default=2, maximum=10).

MIXGDR relative contributions of the GDR and Weisskopf estimates to the E1–γ-strength set to $VAL \cdot GDR + (1 - VAL) \cdot Weiss$. Note that the condition $0 \leq VAL \leq 1$ must be fulfilled (allowed from 0 to 1. default = 1 means pure GDR).

MIXGMR relative contributions of the GDR and Weisskopf estimates to the M1–γ-strength set to $VAL \cdot GDR + (1 - VAL) \cdot Weiss$. Note that the condition $0 \leq VAL \leq 1$ must be fulfilled (allowed from 0 to 1. default = 1 means pure GMR).

MIXGQR relative contributions of the GDR and Weisskopf estimates to the E2–γ-strength set to $VAL \cdot GDR + (1 - VAL) \cdot Weiss$. Note that the condition $0 \leq VAL \leq 1$ must be fulfilled (allowed from 0 to 1. default = 1 means pure GQR).

GCASC Controls calculation of the γ-cascade in the first compound nucleus

= 0 no γ-cascade (only primary transitions),

= 1 full γ-cascade (primary and secondary transitions)

(default: full γ-cascade in the first Compound Nucleus if the initial excitation energy is less or equal to 20 MeV, otherwise primary transitions only).

Miscellaneous

BNDG Binding energy of ejectile I3 in nucleus Z=I1, A=I2 set to VAL (default calculated internally from RIPL nuclear masses).
Uncertainty of the binding energy in % may be given by I4.

SFACT The removal of the s-wave Coulomb barrier transmission probability and the 1/E dependence of the cross section.

= 1 outputs the S-factor for (x,γ)

= 2 outputs the S-factor for (x,n)

= 3 outputs the S-factor for (x,p)

SHELNO Shell correction read from RIPL database will be multiplied by VAL for the nucleus with Z=I1 and A=I2.
Uncertainty of the shell correction value in % may be given by I4 (default 1.0).
The default value corresponds to the use of RIPL Myers-Swiatecki shell corrections assuming a negligible uncertainty.

JSTAB Rotation stability limit with respect to spin for the nucleus Z=I1 and A=I2,

= 0 spin at which fission barrier (incl. shell correction) disappears (default),

$>$ 0 set to VAL.