Multifaceted Coded Nuclear Data Libraries Assemblage: TENDL-2025

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INTRODUCTION

The multipurpose, multifaceted methodical nuclear data libraries coded by TALYS [1] & databases [2], TEFAL, TASMAN [3] as the Evaluated Nuclear Data Library TENDL has now been released every other year recently. Considerable experience has been acquired during the production years of global repetitive seven incident particles (neutron, proton, deuteron, triton, alpha, helium and gamma induced), application agnostic nuclear data libraries with covariance information up to 200 MeV incident energy on about 2850 ($T½ > 1s$) targets Z=3 ^{6}Li to Z=115 ^{291}Mc. The library information is stored in the ENDF-6 data format [4] explicitly below 30 MeV, implicitly above and now in the GNDS-2.0 format [5]. The robust backbone of this achievement is completeness, quality, upgradability and, most of all, reproducibility and methodology. Since TENDL has been comprehensively embraced by many, quite different applications (accelerator, astrophysics, fusion, fission, medical, experimental, decommissioning, etc.) that require multifaceted nuclear reaction data in various forms, primary and derived, for not only criticality but shielding, transport, radioprotection, transmutation, experimental interpretation, materials or earth sciences. The essential knowledge is not the TENDL libraries themselves, but rather the necessary physics databases and methods, processes, codes, tools and know-how that go into the making of every evaluation of the libraries. Recent efforts have focused on proper assessment of the underlying physics models coding and incorporation of databases information and metrics into the scientific T3 system [3].

NUCLEAR OBSERVABLES FOR SCIENCES AND TECHNOLOGIES

Industry recognized traditional nuclear data libraries (ENDF/B-US; JENDL-Japan; JEFF-OECD, CENDL-China) have been assembled over decades by hand, ‘evaluators’ added nuclides/reactions/energies as and when it was deemed necessary for principally fission, low energy-based applications. The methodology is robust when high-quality, differential and integral experimental data are available and can be successfully embedded in their making; however relative to the total set of target nuclides/reactions/energies and derived data needed for many other applications such as shielding, these libraries are small and incomplete. They generally do not contain any more than a very small fraction of the data, forms and observables needed for other non-operational fission, non-criticality applications: non-elastic double differential data, branching ratio, radionuclides production, gas, emitted particles and recoil spectra, etc. Since many (or most) reactions important for advanced system (shielding, accelerators, fusion, instrumentation and manufacturing, security or astrophysics) have few or no experimental differential data, one cannot rely on these traditional libraries, and an alternative is necessary to explore the broader nuclear landscapes. TENDL-2025 [6] fills the space between on-the-fly high energy spallation-collision models and low energy tables, leads the way scientifically and technologically into chartered and unchartered territory.

The TALYS nuclear models code framework shown in Fig. 1. uses various physical models (theoretical and semi-empirical; Optical, Hauser-Feshbach, Exciton, Hartree-fock, Distorted Wave Born, Fermi gas, ECIS-Equation Couplées en Itération Séquentielles for the Schrodinger, Dirac equations, etc.) to generate part of a nuclear data library. TENDL is a nuclear data library completely covering the nuclide/reaction/energy sets, preventing errors in simulation due to missing or incomplete data sets. As such it can be used directly in both basic physics and novel, modern applications. The 13th version is TENDL-2025, which is based on both default and adjusted parameters of the most recent T3 codes and databases suite: TALYS-2.0, TEFAL-2.0 (ENDF-6 formatter) and TASMAN-2.0, wrapping them all into a Bayesian Monte-Carlo (BMC) loop for uncertainty quantification. Resolved and unresolved resonance parameters are now stored in a database named resonance-tables [3]. Modern Multiphysics system also benefits from the model derived complete variance-covariance information systematically provided through BMC sampling methods that allow them to probe non-experimentally chartered landscape.

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As the making or assemblage of the libraries is driven by technologies, any one enhancement, correction, tweak, being

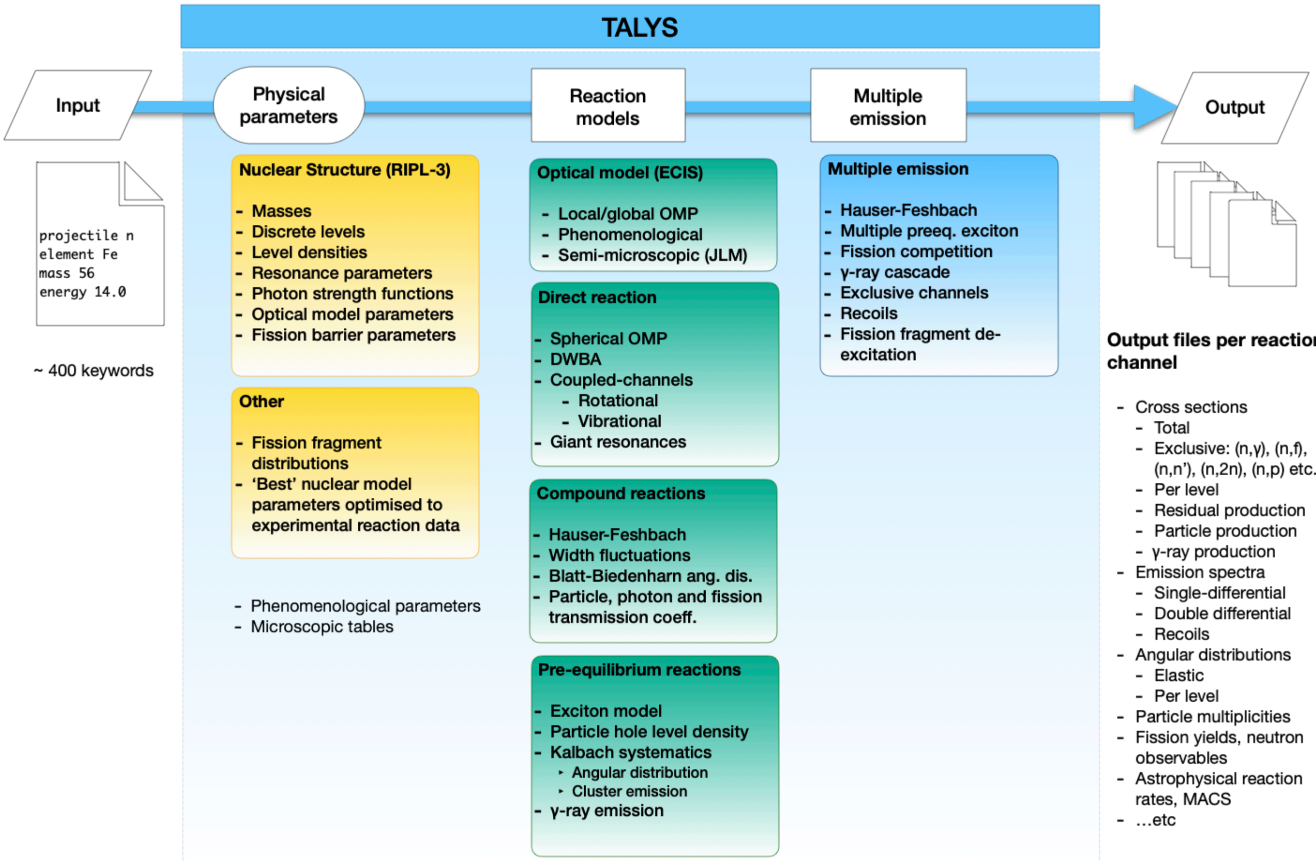

Fig 1. TALYS framework schematics

at the most basic physics and/or format level, is immediately and seamlessly propagated to all targets and data forms. It then can reach the application level forms (processing steps permitting). For the new TENDL-2025 release the following improvements have been made:

- Upgrades to version -2.0 of TALYS, TEFAL, and TASMAN [3], YANDF-0.2 labelling
- Photon strength function QRPA + M1 (Fig. 2.)
- Statistical ensemble of 416 Koning-Delaroche OMP's
- Enhanced, revised resonance parameter database: resonance-tables [3]
- Physics models exploration of the Astrophysics landscape [7]
- Systematics excitation function comparison with experimental information
- ENDF-6 format frame correction of emitted spectra, isomer production, branching ratio
- ENDF-6 explicit-implicit s30 transition mode and GNDS-2.0 forms as default distribution
- Covariances information on all seven incident particles: α, γ, p, d, t, He and n
- Charge particle model adjustments
- Better deuteron and alpha break-up models

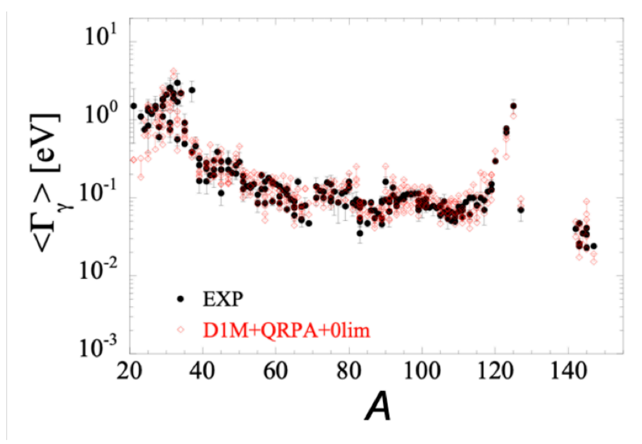

Fig 2. QRPA + M1 upend

Generally, when issues or errors are found in the format and/or physics of one evaluation, a TENDL release, the same issue/error is likely to exist in other evaluations with the same characteristic. Consequently, when corrections or errors are made, they can be propagated to other evaluations in the same manner. It will be fair to recognize that TENDL-2021 and TENDL-2023 still bear the marks of the T3 framework modernisation cycle.

NUCLEAR DATA FORMS FOR APPLICATIONS

The usual ENDF-6 file format in which nuclear data libraries are distributed is typically not sufficient for direct use in many applications, a system of processing modules is needed to convert nuclear data in the ENDF-6 or GNDS format into forms that are usable in practical for applications. Graphical examples from TENDL-2025 [6] of applications libraries forms are shown in Fig. 3-5.

Several processing steps must be taken to satisfy the needs of downstream application codes, some of them being the most basic, such as constructing temperature-dependent linearly interpolable pointwise cross sections from resonance parameters. Others are more complex and targeted toward a specific application; however, those processes always consist of several independent, successive, intertwined tasks able to provide direct and derived data forms to simulation codes that need them. It is remarkable and noteworthy to acknowledge that even for the most processed, handled nuclear data forms in terms of steps, specificity, or complexity, a degree of backward compatibility and cross-checking to basic forms exists. This is a very useful remark that fully integrates what may be seen as rather complex quality assurance, QA or reproducibility processes. Having said that, many end users concentrate on what is defined as cross sections when in fact ones also need emitted particles, residual angular and energy spectra distribution. Other forms such as reaction Q values, energies, prompts, delayed and decay information also co-exist with the above. Different simulations codes usually require different forms, all intended to stem from the same infrastructure.

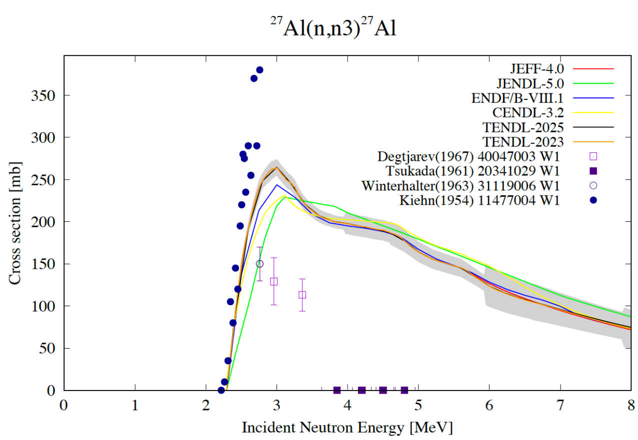

Fig. 3. Al^{27} inelastic to third level with uncertainty bands

The processing trails can deliver the many forms that are useful for all applications. Those forms deepen, enriches, expand the basic raw nuclear data to be efficiently and effectively used in simulations. Regrettably, not all forms can be extracted from every traditional library.

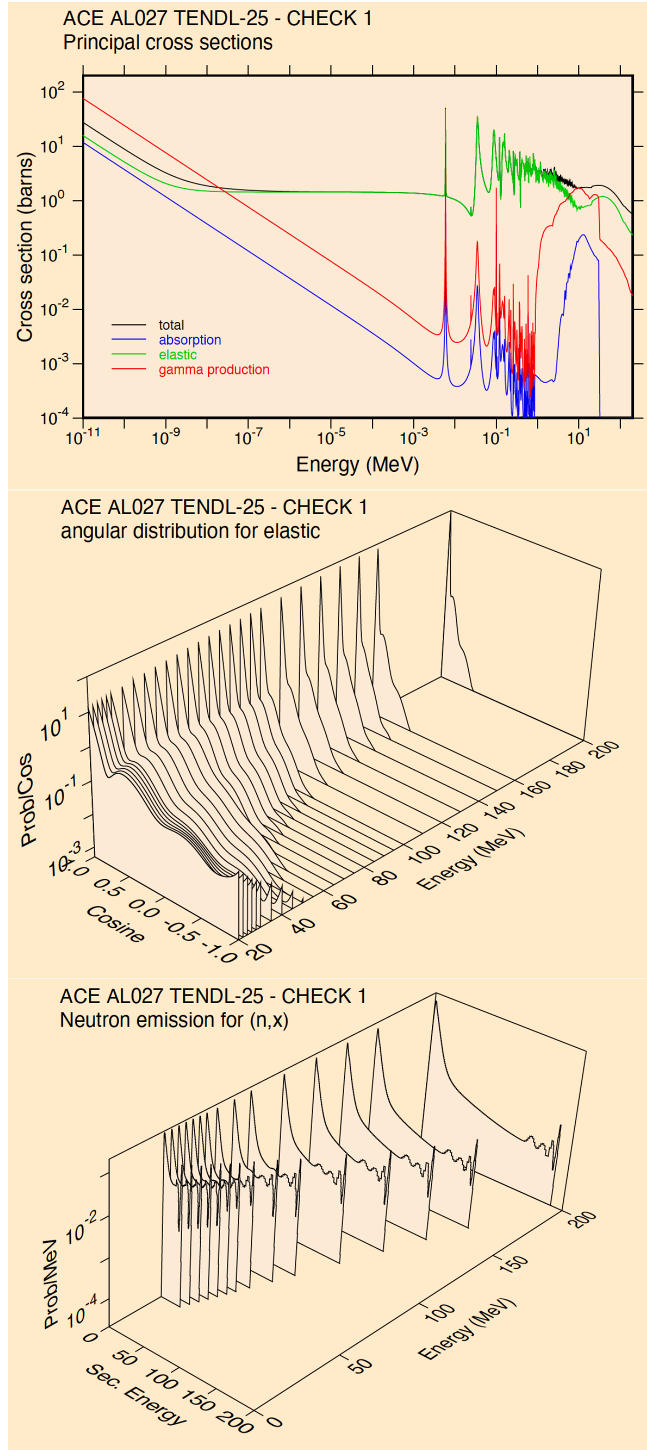

Fig. 4. Al^{27} Cross section, angular, emission distribution.

Applications libraries in continuous NJOY2016-ACE formats for transport, PREPRO-2023 hybrid pointwise, groupwise GENDF formats with CALENDF Self Shielding Factor SSF (neutron induced) for activation-transmutation-material-science systems, KERMA, DPA and gas production responses have been successfully processed, assembled and verified [8]. This is done on at the isotopic target level but also reconstructed for 83-earth bound natural elements.

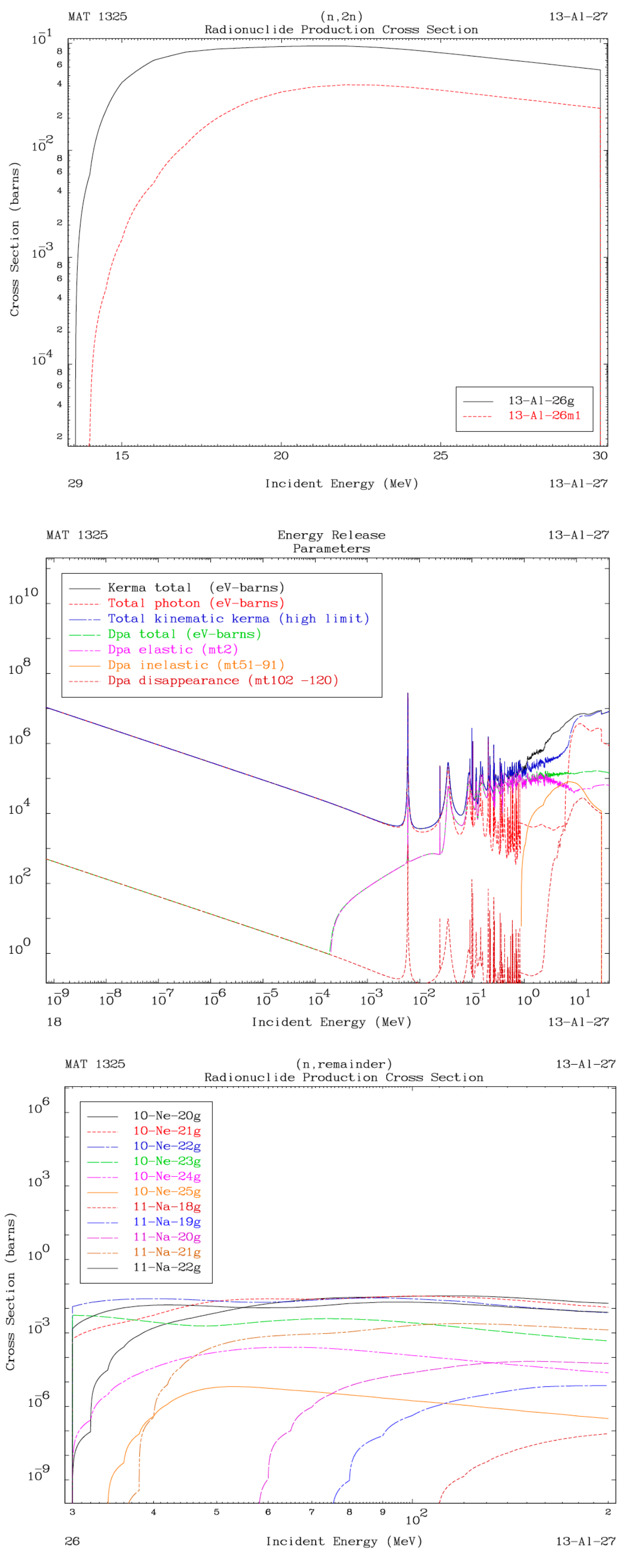

Fig. 5. Al^{27} isomeric, KERMA, DPA responses, implicit above 20 MeV radionuclides production.

RESULTS

TENDL-2025 encompasses 2850 target nuclides, Z=3-115, Lithium to Moscovium, including as target some 519 m (1^{st}), 29 n (2^{nd}) isomeric states (T½ > 1s), for seven incident particles: alpha, gamma, deuteron, proton, helium, triton and neutron up to 200 MeV. TENDL describes all open reaction channels, product yields, emitted spectra, and short-lived daughter radionuclides (T½ > 0.1s) as product and includes complete variance-covariance information derived from reference input parameters variation. When used in conjunction with EXFOR, the primary differential and integral data forms and interpretation can be compared with available experimental information. When fed through application libraries into modern simulation platform such as FISPACT-II, CINDER or ORIGEN (Bateman solver), MCNP6, PHITS, GEANT4 or CERN-FLUKA (as particle transport Boltzmann solvers), or SPECTRA-PKA (primary knock-on atom evaluator), its enhanced nuclear data primary and derived forms enable detailed, consistent and probing studies of the nuclear application landscape like no other, leading the way scientifically and technologically into chartered and uncharted territory.

REFERENCES

1. A. KONING, S. HILAIRE, S. GORIELY, "TALYS: modelling of nuclear reactions", Eur. Phys. J. A (2023) **59**: 131 https://doi.org/10.1140/epja/s10050-023-01034-3
2. D. ROCHMAN, A. J. KONING, J.-Ch. SUBLET, "A Statistical Analysis of Evaluated Neutron Resonances with TARES for JEFF-3.3, JENDL-4.0, ENDF/B-VIII.0 and TENDL-2019," Nucl. Data Sheets 163 (2020) 163-190
3. TALYS-Related Software and Databases https://www-nds.iaea.org/talys/
4. "ENDF-6 Format Manual", BNL-224854-2023-INRE (2023).
5. "Specifications for the Generalised Nuclear Database Structure (GNDS)" Version 2.0 NEA (2023).
6. A. J. KONING and D. ROCHMAN, "TENDL-2025: TALYS-based Evaluated Nuclear Data Library," (2025) https://tendl.web.psi.ch/tendl_2025/tendl2025.html
7. "TENDL-Astrophysics", https://tendl.web.psi.ch/tendl_2023/astro/astro.html
8. Processing Software's: NJOY-2016, PREPRO-2023 and CALENDF-2010