Introduction to the ENDF format
Reading and Manipulating ENDF files with ENDFtk

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2022 MCNP User Symposium, October 17-21, 2022
Outline

• Introduction
• What is ENDF?
• Overview of the ENDF format and structure
• The ENDFtk toolkit
Introduction

- Nuclear data is everything needed to describe particle transport and nuclear processes
  - Nuclear reaction data
  - Cross sections, secondary particle angular distributions, etc.
  - Radioactive decay data
  - Uncertainties (covariance data)

- Used by particle simulation codes at LANL
  - Monte Carlo particle transport with MCNP
  - Deterministic particle transport with PARTISN
  - Material irradiation with CINDER
What is ENDF?

• ENDF = Evaluated Nuclear Data File/Format

• Evaluated Nuclear Data Format
  - Format specification for storing/organising nuclear data
  - Format versions are designated with an Arabic number
    - ENDF-6 is the current format version

• Evaluated Nuclear Data File
  - The name of the US nuclear data library
  - Library versions are designated with a Roman numeral
    - ENDF/B-VIII.0 is the latest version, released in February 2018
    - ENDF/B-VIII.1 is currently in beta, to be released in 2024
What is ENDF?

• ENDF was created in the mid-1960s
  - The format has gone through 6 iterations
  - Used for 8 generations of the ENDF/B library
    ▪ ENDF/B-I in July 1968
    ▪ ENDF/B-VIII.0 in February 2018
    ▪ The future ENDF/B-VIII.1 library

• ENDF is developed and maintained by the NNDC and coordinated by CSEWG
  - NNDC: National Nuclear Data Centre at BNL
  - CSEWG: Cross Section Evaluation Working Group
    ▪ Collaboration between national labs, universities and nuclear industry from the US and Canada
    ▪ International organisations such as the International Atomic Energy Agency (IAEA)
What is ENDF?

• The ENDF format is the de facto standard for all nuclear data libraries

• There are multiple “independent” libraries
  – Europe: Joint European Fission and Fusion (JEFF)
  – Japan: Japanese Evaluated Nuclear Data Library (JENDL)
  – China: Chinese Evaluated Nuclear Data Library (CENDL)
  – Russia: BROND

• All libraries are freely available from different nuclear data centres:
  – In the US, this is the NNDC at Brookhaven National Laboratory (BNL)
  – There are many data centres in the world: OECD/NEA, IAEA/NDS, etc.
What is ENDF?

If you can read this, you are ready to join the nuclear data team. Send an email to nucldata@lanl.gov to apply.
Overview of the ENDF format and structure

• An ENDF library has multiple sub-libraries
  - Incident particle data: n, p, d, t, $^3$He, $\alpha$
  - Photonuclear and photoatomic data
  - Thermal scattering data for crystals and molecules
  - Radioactive decay data
  - Neutron induced and spontaneous fission yields
  - Atomic relaxation data
  - Electron interaction data

• Each sub-library is physically separated and stored in one or more “tapes”
  - ENDF jargon dating back to the time of magnetic tapes and punch cards
Overview of the ENDF format and structure

• Each tape is structured as a sequence
  - Materials designated by the MAT number
  - Files designated by the MF number
  - Sections designated by the MT number
  - A section is a sequence of records
Overview of the ENDF format and structure

• A material is identified by its **MAT** number
  - A specific nuclide, an element, a molecule, etc.
  - Between 1 and 9999

• Some sublibraries impose rules for isotopes
  - $Z \times 100 + 25$ for the first stable isotope
  - Decremented/incremented for the previous/next isotope
  - Numbers in between for metastable states
  - For example:
    - 125 for H1, 9228 for U235
    - 9546 for Am242, 9547 for Am242m
Overview of the ENDF format and structure

• Files identified by their MF number store specific types of data:
  - MF1: descriptive and miscellaneous data
  - MF2: resonance parameters
  - MF3: cross section data
  - MF4: secondary particle angular distribution
  - MF5: secondary particle energy distribution
  - MF6: correlated secondary particle angle-energy distribution
  - MF7: thermal scattering data
  - MF8: radioactive decay data
  - MF12 to MF15: photon data
  - MF31 to MF35: covariance data
  - And there are even more …
Overview of the ENDF format and structure

• Sections designated by an MT number store specific “reaction data”
  
  • These can be “simple” reactions
    − MT102 (neutron capture), MT51 to MT91 (inelastic levels)
  
  • These can be “summation” reactions
    − MT4 (inelastic scattering, sum of MT51 to MT91)
  
  • These can be “special” sections
    − MT451 (descriptive data, only in MF1)
    − MT151 (resonance parameters, only in MF2)

• MT numbers are limited to 1–999
Overview of the ENDF format and structure

• Only 6 record types to store information:
  - TEXT: stores just text
  - CONT: 2 floating point numbers and 4 integers
  - LIST: a list of values
  - TAB1: a one dimensional function $y = f(x)$
  - TAB2: a two dimensional function $z = f(x,y)$, used in combination with other records
  - INTG: a correlation matrix (used for covariance data)

• Special cases:
  - HEAD: a CONT record at the beginning of each section
  - TEND, MEND, FEND, SEND: records to signal the end of a tape, material, file or section
Overview of the ENDF format and structure

- Lines consisting of 80 characters
  - Six 11 characters columns for floats and integers
  - Four columns for the MAT, MF, MT and sequence number
The ENDFtk toolkit

- **ENDFtk:** [https://github.com/njoy/ENDFtk](https://github.com/njoy/ENDFtk)
  - A format component developed in the NJOY modernisation project
  - Reading, writing and manipulate ENDF files
  - Using a C++ and Python API at the same time

<table>
<thead>
<tr>
<th>MF</th>
<th>Description</th>
<th>ENDFtk support</th>
<th>Python support</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General information</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>2</td>
<td>Resonance parameters</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>3</td>
<td>Reaction cross sections</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>4</td>
<td>Angular distributions</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>5</td>
<td>Energy distributions</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>6</td>
<td>Product energy-angle distributions</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>7</td>
<td>Thermal neutron scattering law data</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>8</td>
<td>Decay and fission product yields</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>9</td>
<td>Multicencies of radioactive products</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>10</td>
<td>Radioactive nuclide production</td>
<td>Full</td>
<td>Full</td>
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<tr>
<td>12</td>
<td>Photon production yield data</td>
<td>Full</td>
<td>Full</td>
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<tr>
<td>13</td>
<td>Photon production cross sections</td>
<td>Full</td>
<td>Full</td>
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<tr>
<td>14</td>
<td>Photon angular distributions</td>
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<td>Full</td>
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<tr>
<td>15</td>
<td>Continuous photon energy spectra</td>
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<tr>
<td>23</td>
<td>Photon interaction cross sections</td>
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<td>Photo-atomic distributions</td>
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<td>Atomic form factor functions</td>
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<td>Atomic relaxation data</td>
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<td>Full</td>
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<td>30</td>
<td>Covariance of model parameters</td>
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<td>None</td>
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<tr>
<td>31</td>
<td>Covariances of fission</td>
<td>Soon</td>
<td>Soon</td>
</tr>
<tr>
<td>32</td>
<td>Covariances of resonance parameters</td>
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<td>35</td>
<td>Covariances of energy distributions</td>
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<tr>
<td>40</td>
<td>Covariances for nuclide production</td>
<td>Soon</td>
<td>Soon</td>
</tr>
</tbody>
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The ENDFtk toolkit

• Prerequisites:
  - git
  - cmake 3.15 or higher
  - a C++-17 compliant compiler such as gcc-7 or higher
  - Python 3.5 or higher

• Installation instructions:

```
git clone https://github.com/njoy/ENDFtk
cd ENDFtk
git checkout develop
mkdir build
cd build
cmake -DCMAKE_BUILD_TYPE=Release ..
make ENDFtk.python -j8
```