# Fission Yield Interpolation and Energy Dependent Fission Product Yield Covariance Format

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Nuclear Data Week 2025 – January 6 – 9, 2026

LA-UR-26-20127

Los Alamos
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# Fission Product Yield Interpolation

# The current format and manual recommend linear interpolation between incident energies

- From the ENDF-6 manual:

```
[MAT, 8, MT/ ZA, AWR, LE+1, 0,  0,   0]HEAD
[MAT, 8, MT/ E1, 0.0,   LE, 0, NN, NFP/ Cn(E1) ]LIST
[MAT, 8, MT/ E2, 0.0,    I, 0, NN, NFP/ Cn(E2) ]LIST
[MAT, 8, MT/ E3, 0.0,    I, 0, NN, NFP/ Cn(E3) ]LIST
  ------------------------
[MAT, 8, 0 /0.0, 0.0,    0, 0,  0,   0]SEND
```

$\mathbf{I}_i$ Interpolation scheme (see paragraph on Two-dimensional Interpolation Schemes in Section 0.5.2) to be used between the $E_{i-1}$ and $E_i$ energy points.

Yields for the same fission product nuclides should be given at each energy point. This will facilitate interpolation of yield data between incident energy points. Also, a linear-linear interpolation scheme should be used.

# But most evaluators recommend *not interpolating at all* for previous evaluations

- The incident energies are “effective” energies representing a spectrum
  - Are there any cases for which this is not true?

- The new LANL FPY’s are energy-dependent, and linear interpolation can be performed between the incident energies

- How can this be communicated?

# ENDF-6 Format Change

- A new flag in the HEAD record to indicate if interpolation is recommended:
  - 0 : not recommended (“effective” energies)
  - 1 : recommended by the law given in the LIST records

```
[MAT, 8, MT/ ZA, AWR, LE+1, 0, 0, 0]HEAD
[MAT, 8, MT/ E1, 0.0, LE, 0, NN, NFP/ Cn(E1) ]LIST
[MAT, 8, MT/ E2, 0.0, I, 0, NN, NFP/ Cn(E2) ]LIST
[MAT, 8, MT/ E3, 0.0, I, 0, NN, NFP/ Cn(E3) ]LIST
-------------------------
[MAT, 8, 0 /0.0, 0.0, 0, 0, 0, 0]SEND
```

# GNDS Format Change

- The format currently does not hold any interpolation information (not in an `XYs2d`)
- Could an `interpolation` attribute be added to the `<incidentEnergies>` node?
- Or should <`incidentEnergies`> be changed to an `XYs2d`?
- This will be brought up at the EG-GNDS meeting in May 2026

```
<fissionFragmentData>
  <delayedNeutrons>...</delayedNeutrons>
  <fissionEnergyReleased>...</fissionEnergyReleased>
  <productYields>
    <productYield label="eval">
      <nuclides> V66 V67 Cr66 ... </nuclides>
      <elapsedTimes>
        <elapsedTime label="initial">
          <time>
            <double label="initial" value="0.0" unit="s"/></time>
          <incidentEnergies>
            <incidentEnergy label="0">
              <energy>
                <double label="0" value="500000.0" unit="eV"/></energy>
              <yields>
                <nuclides href="../../../../../../nuclides"/>
                <values>1.87064e-17 2.02328e-18 6.25013e-13 ... </values>
                <uncertainty>
                  <covariance>
                    <array shape="1267,1267" compression="diagonal">
                      <values>...</values></array></covariance>
                </uncertainty>
              </yields>
            </incidentEnergy>
            <incidentEnergy label="1">...</incidentEnergy>
```

# Energy Dependent Fission Product Yield Covariances

# A format is needed for FPY Covariances

- File 8 holds fission product yield uncertainties, but not correlations

- Considerations:
  - Backward compatible with uncertainties in MF8
  - Not a compact format
  - Allow cross-correlations between energies and MT's
  - Hold incident-energy grouped covariances (like File 33)

# ENDF-6 Format Proposal

- Leave uncertainties in File 8 in the point-wise structure
  - Allow linear interpolation on the absolute uncertainty values
- Put correlations only in File 38 in a grouped structure
- Require the same list of nuclides in both for all energies and MT's

The structure of a section is:

[MAT, 38, MT/ ZA, AWR, 0, 0, NB, 0] HEAD
[MAT, 38 ,MT/ 0.0, 0.0, 0, 0, NG+1, 0/ $E_l$]LIST
[MAT, 38 ,MT/ 0.0, 0.0, 0, 0, 2*NFP, NFP/ $ZAFP_l$, $FPS_l$]LIST
<NB subsections>
[MAT, 38, MT/ 0.0, 0.0, 0, 0, 0, 0] SEND

Subsections

Each subsection represents a single submatrix of the full correlation matrix, associated with a given row and column energy group. Each subsection has the following structure:

[MAT,38, MT/ IROW, ICOL, LS, 0, NT, 0/ $C_l$]LIST

# GNDS Format Proposal

- The FPY objects already hold covariances within a single incident energy
- For cross-correlations (different energies):
  - Make use of `rowData` and `columnData` attributes
- This will be brought up at the EG-GNDS meeting in May 2026

```
<fissionFragmentData>
  <delayedNeutrons>...</delayedNeutrons>
  <fissionEnergyReleased>...</fissionEnergyReleased>
  <productYields>
    <productYield label="eval">
      <nuclides> V66 V67 Cr66 ... </nuclides>
      <elapsedTimes>
        <elapsedTime label="initial">
          <time>
            <double label="initial" value="0.0" unit="s"/></time>
          <incidentEnergies>
            <incidentEnergy label="0">
              <energy>
                <double label="0" value="500000.0" unit="eV"/></energy>
              <yields>
                <nuclides href="../../../../../../nuclides"/>
                <values>1.87064e-17 2.02328e-18 6.25013e-13 ... </values>
                <uncertainty>
                  <covariance>
                    <array shape="1267,1267" compression="diagonal">
                      <values>...</values></array></covariance>
                </uncertainty>
              </yields>
            </incidentEnergy>
            <incidentEnergy label="1">...</incidentEnergy>
```

# Example File with 3 Energy Groups

- $^{235}$U energy-dependent FPY's
- 21 energies in File 8
- 859 nuclides, consistent across all energies and MT's
- 3 energy bins in File 38
- Cross-correlations between all nuclides and energy bins
- Correlations for Independent and Cumulative, no cross-correlation between them
- File size: 144MB

# Saving Space

- Store a limited set of eigenvalues and eigenvectors of the matrices
  - The evaluators would choose how many are needed

- Relax the requirement of having the same list of nuclides in File 8 and File 38
  - The evaluators would provide a default correlation value to use