ENDF/B-VII.1 Beta Zr and Hf Testing at Bettis

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Testing

- Performed sensitivity study of ENDF/B-VII.1 Beta Zr and Hf using our Proprietary NNPP Benchmarks
  - 160 configs in benchmark suite
  - Cold, warm, hot temperatures
  - Sensitive to Zr and Hf cross sections
- Zr evaluations tested
  - ENDF/B-VII.0 Zr
  - JENDL-4.0 Zr
  - ENDF/B-VII.1 (Beta 2) Zr
  - ENDF/B-VII.1 (Beta 3) Zr
  - ENDF/B-VII.1 (Beta 4) Zr
- Hf evaluations tested
  - ENDF/B-VII.0 Hf
  - ENDF/B-VII.1 (Beta 2) Hf
  - JENDL-4.0 Hf
  - JEFF-3.1 Hf
- Evaluated k_{crit} correlation to:
  - Above Thermal Leakage Fraction (ATLF)
  - Above Thermal Fission Fraction (ATFF)
  - Temperature
  - Multiple linear regression
- MC21 Version 3.02

Test Matrix

Base Cross Sections		Zr					Hf			
ENDF70	ENDF71 .Beta2 + E70 ^{16}O	ENDF70	ENDF71 .Beta2	ENDF71 .Beta3	ENDF71 .Beta4	JENDL-4.0	ENDF70	ENDF71 .Beta2	JENDL-4.0	JEFF-3.1
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ENDF/B-VII.0 Results

- Base ENDF/B-VII.0 cross sections
  - ATLF trend
  - ATFF trend
  - No temperature trend
  - Small k_{crit} bias
  - Zr cross sections suspect
- Substituted JENDL-4.0 Zr and JEFF-3.1 Hf into ENDF/B-VII.0
  - Eliminated ATFF trend
  - Reduced k_{crit} bias
  - Small increase in ATLF trend
  - Indications that JENDL-4.0 Zr ESAD too forward peaked below 1 MeV

ENDF/B-VII.1 Beta 2 Zr and Hf Results

- Beta 2 Zr and Hf (WRT ENDF70)
  - Increased k_{crit} bias
  - Reduction in ATFF trend
    - ~2/3 of ENDF70 ATFF trend
  - Introduces small but statistically significant temperature trend
- JENDL-4.0 Zr sensitivities indicate
  - Beta 2 Hf primarily responsible for increased k_{crit} bias
  - Beta 2 Hf responsible for ~1/2 of ATFF trend
- Beta 2 Zr ESAD (more later)
  - Slightly backscattered at low energies (negative P_1 moment)
  - Does not converge to isotropic at low energies (10^{-5} eV)
  - Suspect numerical issue

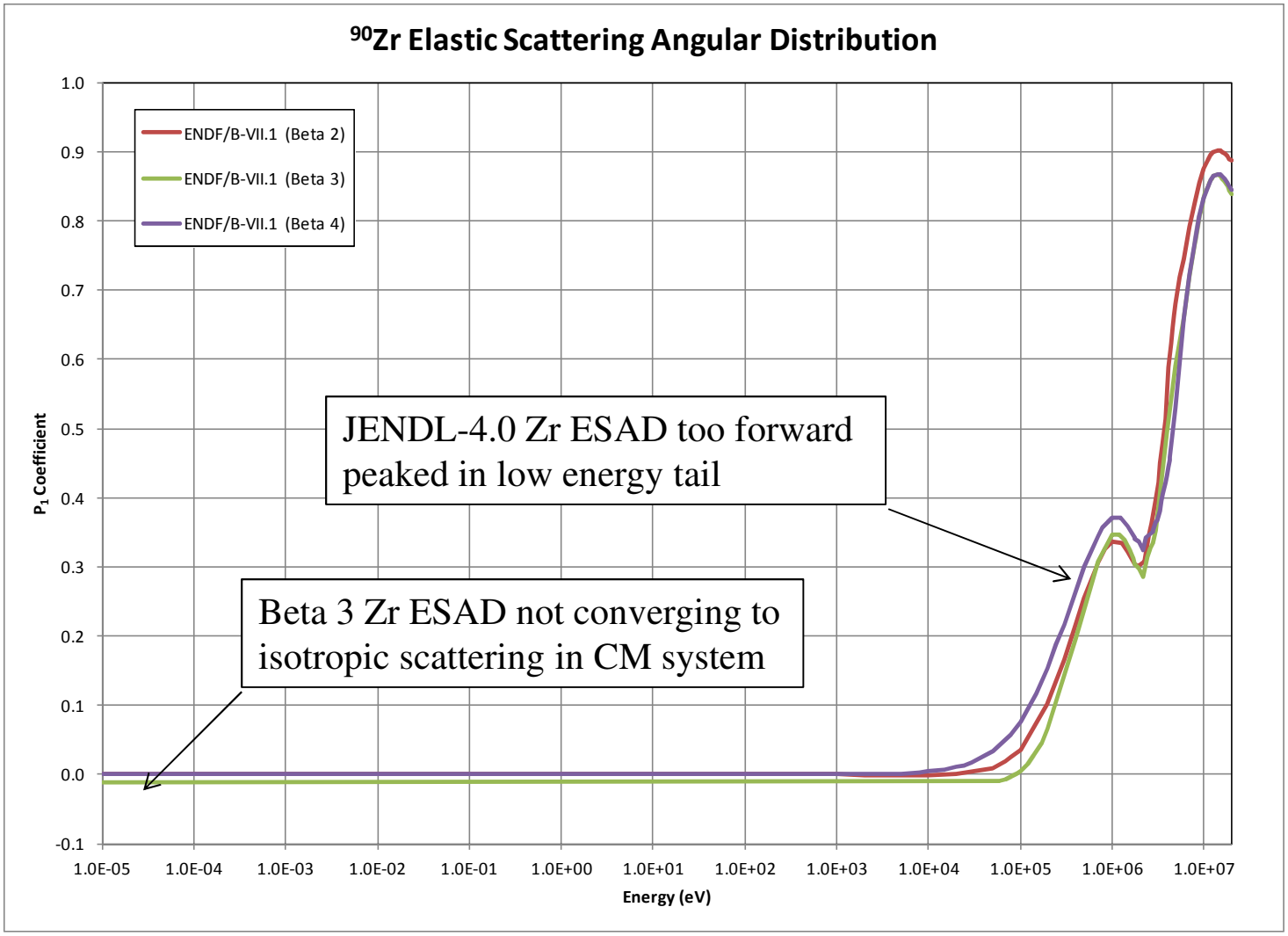
ENDF/B-VII.1 Beta 3 Zr Results

- **Beta 2 Hf Results**
  - Increased k_{crit} bias
  - Reduced ATFF trend
  - Small temperature trend
- **JENDL-4.0 Hf Results**
  - Reduced k_{crit} bias
  - Small increase in ATLF trend
  - Statistically insignificant ATFF trend
  - Small temperature trend
- **JEFF-3.1 Hf Results**
  - Reduced k_{crit} bias (brackets unity)
  - Small increase in ATLF trend
  - Eliminates ATFF trend
  - Small Temperature trend
- **Beta 3 Zr + (JENDL-4.0 Hf | JEFF-3.1 Hf)**
  - Either combination OK
  - Improvement upon ENDF70
  - JEFF-3.1 Hf slightly more reactive
- **Beta 3 Zr Observations**
  - ATFF and Temperature trend implies still room for improvement in resonance range for BNL Zr
  - ATFF and Temperature trend eliminated using JENDL-4.0 Zr
  - Suggest understanding differences in BNL and JENDL-4.0 Zr resonance range

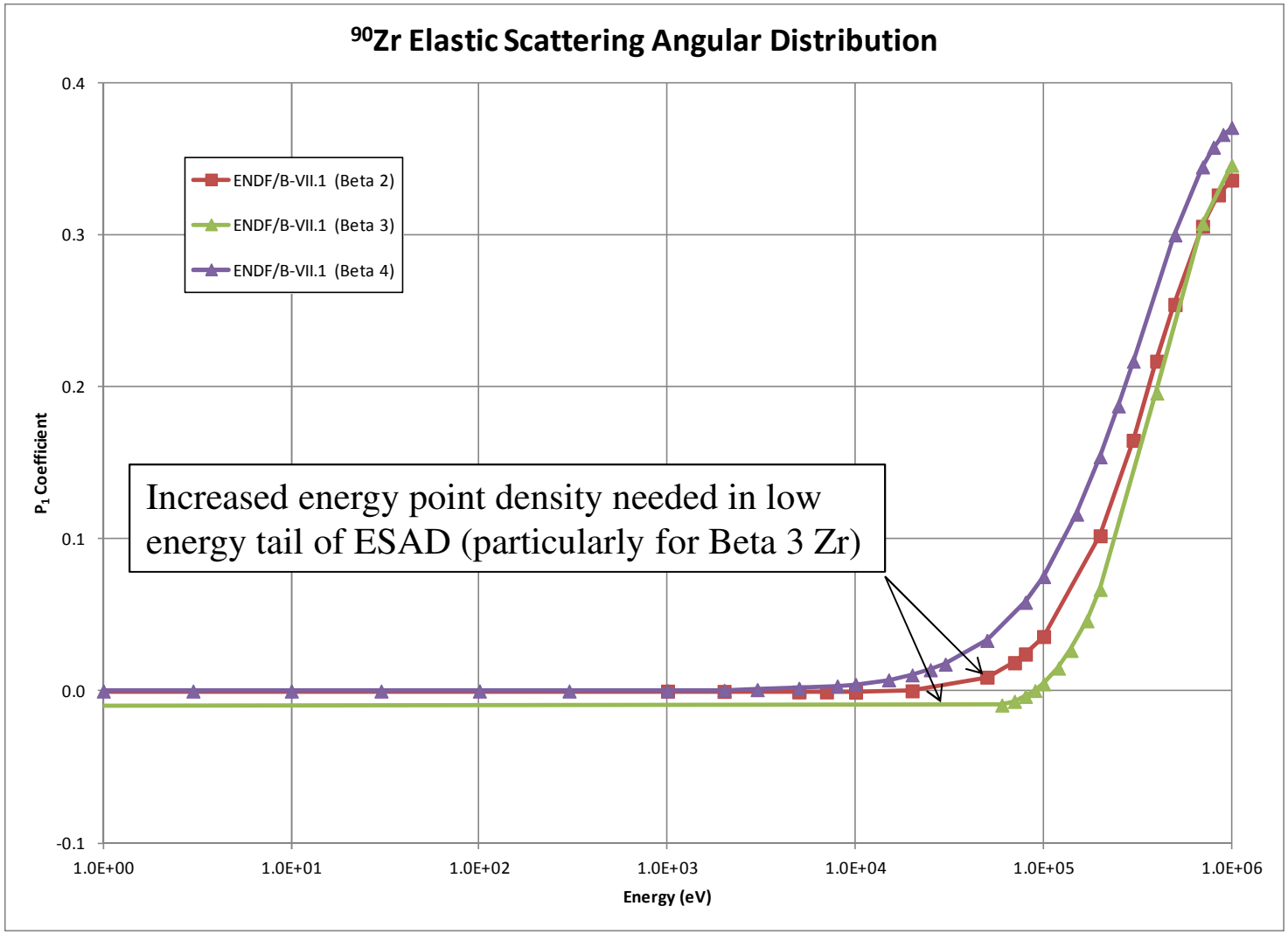
ENDF/B-VII.1 Beta 4 Zr Results

- **Beta 2 Hf Results**
  - Large k_{crit} bias
  - Increase in ATLF trend
  - Reduced ATFF trend (~2/3 ENDF70)
  - Small temperature trend
- **JENDL-4.0 Hf Results**
  - Large k_{crit} bias (slightly reduced)
  - Increase in ATLF trend
  - Reduced ATFF trend (~1/3 ENDF70)
  - Small temperature trend
- **JEFF-3.1 Hf Results**
  - Medium k_{crit} bias (slightly reduced)
  - Increase in ATLF trend
  - Eliminates ATFF trend
  - Small Temperature trend
- **Beta 4 Zr step backward**
- **JENDL-4.0 Zr ESAD**
  - Appears to be too forward peaked in low energy tail (<1MeV)
  - Produces excessive leakage
  - Responsible for increase in k_{crit} bias and ATLF trend
- **NNPP benchmarks tend to support ENDF Zr ESAD**
  - Need increased (JENDL-4.0 like) energy point density in low energy tail for thermal reactor applications

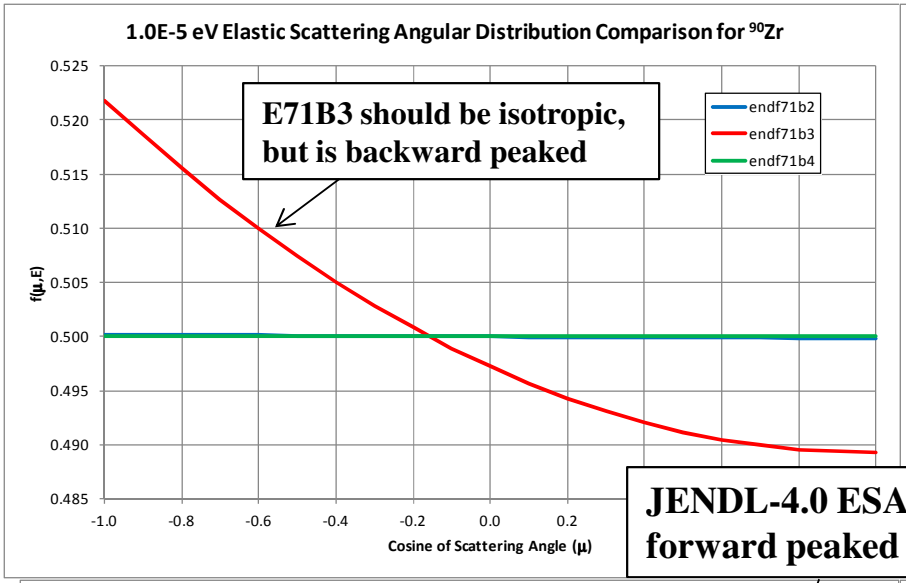
ENDF/B-VII.1 Beta Zr ESAD Observations

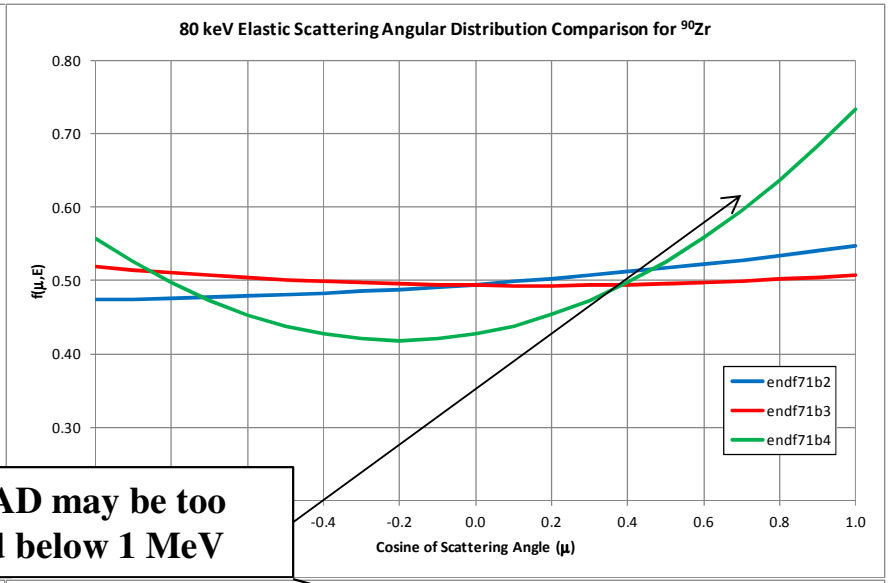


ENDF/B-VII.1 Beta Zr ESAD Observations

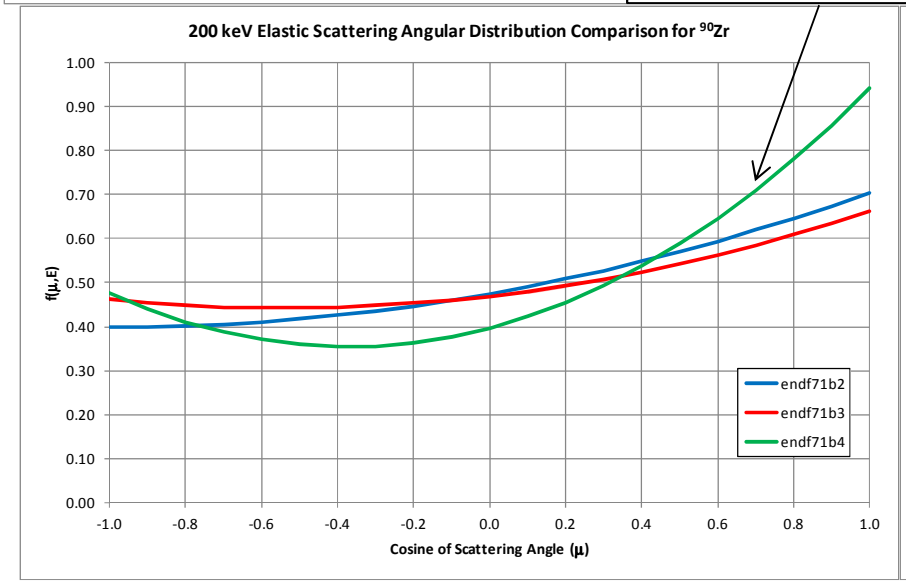


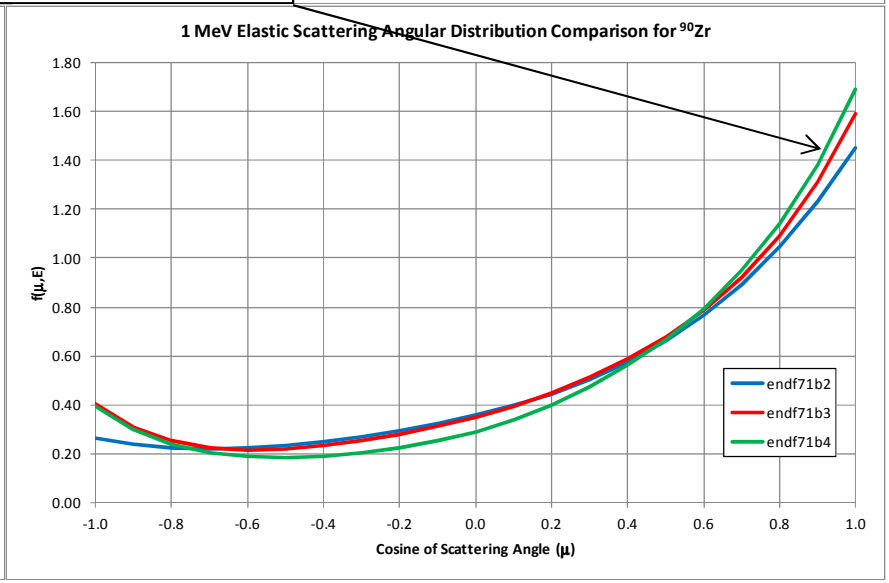
ENDF/B-VII.1 Beta Zr ESAD Comparisons





JENDL-4.0 ESAD may be too forward peaked below 1 MeV





Conclusions

- **Bettis NNPP benchmark testing supports Beta 3 Zr with either JENDL-4.0 or JEFF-3.1 Hf**
  - Suggest fixing low energy tail in Zr ESAD
- **JENDL-4.0 (Beta 4) Zr ESAD too forward peaked < 1 MeV**
  - Results in excessive leakage
  - Increases ATLF trend and k_{crit} bias
- **Beta 2 Hf appears to be too absorbing**
  - Bettis prefers either JENDL-4.0 or JEFF-3.1 Hf
  - JEFF-3.1 Hf slightly more reactive than JENDL-4.0 Hf

Zr Conclusions

- **Still room for improvement in ENDF Zr**
  - Understand differences between BNL and JENDL-4.0 Zr resonance parameters
  - May be able to eliminate ATFF and Temperature trends in BNL Zr
  - NNPP benchmarks tends to support ENDF Zr ESAD
  - Increase energy point density in low energy tail of ESAD to support thermal reactor applications
  - ESAD converges to isotropic at low energies (10^{-5} eV)

- **Suggest looking at JENDL-4.0 Zr + ENDF Zr ESAD**
  - Use JENDL-like energy point density in low energy tails of ESAD
  - Fix ESAD so converges to isotropic at low energies (10^{-5} eV)