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STATUS AND ANALYSIS OF P1 ANGULAR SCATTERING SENSITIVITY DATA AVAILABLE WITHIN THE DATABASE FOR ICSBEP (DICE)

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Abstract – *The sensitivity coefficient to changes in P1 elastic scattering data have been calculated for 368 ICSBEP benchmarks by converting MCNP cosine bin elastic scattering sensitivity coefficients to the equivalent coefficients in Legendre polynomials, which is the same form as the majority of angular nuclear data and their uncertainties. Numerical convergence of the algorithm was examined by varying the number of neutron histories, the number of cosine bins and energy grid spacing for both the sensitivity coefficients and cross section tabulation, as well as the integration parameters, to gauge the reliability of the computed P1 sensitivity coefficients. This data has been recently incorporated into the database for ICSBEP, DICE. P1 elastic scattering sensitivity data is now available as a parameter for users to search for benchmarks, facilitating the identification of suitable benchmarks to test changes in nuclear data evaluations of P1. This work also briefly examines combining the sensitivity coefficients with a covariance file, to perform an uncertainty analysis estimate of the nuclear data uncertainty originating from P1.*

I. INTRODUCTION

Nuclear data validation requires the selection of appropriate experiments. It is desirable that all important phenomena are adequately represented in a validation test suite. Fortunately a wide range of benchmarks are available in the ICSBEP [1] Handbook, spanning the majority of important isotopes and reactions; furthermore of the nearly 5000 benchmarks in the Handbook, over 4000 benchmarks are accompanied by their corresponding nuclear data sensitivity file to assist in the selection process [2]. The ability to identify relevant experiments is not perfect, and some important reactions are missing from the sensitivity data. One such missing piece of information is the sensitivity of the benchmarks to the angular distribution in the nuclear data files. Recently a renewed effort to add the functionality in Monte Carlo codes to calculate sensitivity profiles to elastic scattering angular distributions has been tested in various codes [3,4,5]. This paper provides Monte Carlo computed sensitivities to elastic angular scattering for 368 ICSBEP benchmarks, available in the database for ICSBEP, DICE, to help identify experiments that could be used to improve benchmarking.

II. DESCRIPTION OF THE ACTUAL WORK

Using MCNP6.1 [6] and JANIS [7], the P1 elastic scattering sensitivity profiles of PU-MET-FAST, HEU-MET-FAST, and HEU-MET-THERM benchmarks were calculated using the method outlined in Ref 5. Previously it was noted [3] that fast benchmarks have a higher sensitivity to angular scattering compared to thermal systems, owing to the prevalence of isotropic scattering (P1 ~0) at thermal energies, while fast systems can exhibit a high sensitivity to angular data, especially benchmarks with a significant amount of leakage, which enhances the importance of whether a neutron is forward or backward scattered.

Although likely to change in the near future, computing elastic P1 sensitivity coefficients is still a non-trivial exercise. Aufiero et al. [4] correctly highlight that the discretization process can impede the accuracy of the results, however in this work we are ultimately concerned with providing a large number of sensitivity coefficients for the purposes of searching a database, so our application can tolerate a less precise answer than what may be required for an application such as nuclear data adjustment. Even so, during the generation of the sensitivity coefficients the numerical convergence to both the energy and angular grids was studied to provide confidence in the numerical convergence and this work comprises the first part of the paper. Subsequently an overview of the 368 cases in DICE for which P1 elastic scattering sensitivity data was computed is discussed and finally an assessment of the relative magnitude of the impact in uncertainty analysis is provided.

1. Numerical Convergence Testing

In the MCNP6/JANIS method to map cosine bin sensitivities to the Legendre equivalent, the elastic scattering cross section σ_j^0, the double differential cross section $\sigma_{i,j}^0$ and the Legendre coefficient from P1 are required, and are provided by JANIS, although any nuclear data tool able to provide cross sections on an arbitrary energy/angle grid could be used. As for the $S_{i,j}$ sensitivity coefficients, they were computed in cosine bins on an energy grid using MCNP6. Ideally, the coefficients would

be computed directly in MCNP, however at this time only a developmental version with this capability exists [3].

The equation to compute P1 sensitivity coefficient is:

$$\frac{3}{2}\sum_{i=0,j=0}^{N,M}\frac{\frac{\sigma_j^0}{2\pi}a_{1,j}P_1(j)}{\sigma_{i,j}^0}S_{i,j} = \text{P1 sensitivity} \quad \textbf{(1)}$$

Where j are energy nodes, i are angular bins, $a_{l,j}$ are the Legendre coefficients, and the flow of information is shown in Fig 1. This equation represents a basic mapping of cosine bin sensitivities to P1 sensitivities and could also be used for higher order Legendre coefficients, although this has not been studied.

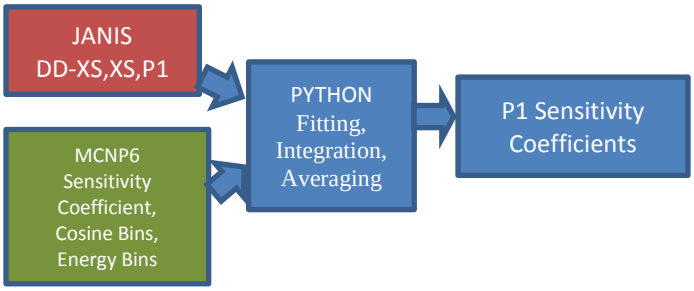

Fig. 1. Color coded process of computing P1 sensitivity coefficients

A number of parameters have been discretized, which impacts the accuracy of the computation. Firstly, the method requires nuclear cross sections. In JANIS, the user has the option to choose an energy grid for the elastic scattering cross section, and an energy/angle grid for the double differential elastic scattering cross section. Secondly, the method requires the cosine bin sensitivity coefficients and with MCNP6 the user chooses the energy and angle grid, as well as the number of neutron histories. The equation is then computed using python, which performs the interpolation of cross sections using ***'RectBivariateSpline'***. Within the function, the degree of the spline can be varied, and the spline is then integrated using the ***'quad'*** function and subsequently averaged to obtain the change in cross section on a grid matching the sensitivity grid.

To test the impact of the various options in the above algorithm used to compute the P1 elastic scattering sensitivity coefficient, the benchmark PMF026-001 from the ICSBEP handbook was selected, for reasons that will be described in the next section, and three isotopes were examined, Fe^{56}, $Pu^{239}$and Pu^{240}.

A. Cross Section Options Used in JANIS

As discussed in the previous section, Fe^{56}, $Pu^{239}$and Pu^{240} were deliberately chosen, and the cross sections and sensitivity coefficients were computed using ENDF/B-VII.0 data. Experience from previous work [5] compared derived P1 coefficients to direct perturbations in the ENDF data for bare plutonium spheres and led to the expectation that the method would work well for Pu.

Plutonium isotopes, like most others, have resolved resonance regions that end in the tens or hundreds of keV after which, the cross section is relatively smooth. It was thought that the algorithm could suffer for isotopes with resolved resonance regions (RRR) that extend close to the MeV region as this energy region is dominant for the total P1 elastic scattering coefficient. This high energy RRR is an atypical situation in current ENDF/B libraries, however Fe^{56} is a prominent example of an isotope with a RRR extending to the MeV range, see Fig. 2 depicting the elastic scattering cross sections of the three isotopes studied. This led to the selection of PMF026 as a test benchmark; a plutonium sphere reflected by iron, which was thought to have the highest Fe^{56} P1 sensitivity coefficient of the 368 cases computed.

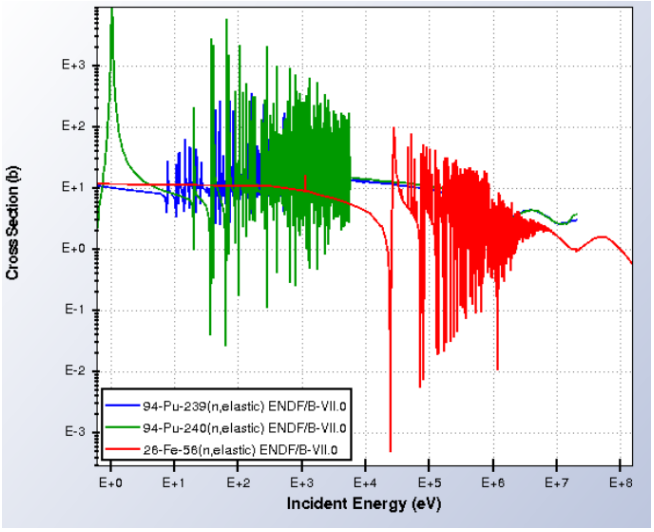

Fig. 2. Elastic scattering cross section of the test isotopes, illustrating the extended resolved resonance region for Fe^{56}, when compared to Pu^{239}, and Pu^{240}.

Five cases using different discretization of the energy and angular grids used in JANIS were studied:

- **Case** A: Cross section spacing 100 intervals per decade, cosine bin spacing 0.01
- **Case** B: Cross section spacing 100 intervals per decade, cosine bin spacing 0.02
- **Case C:** Cross section spacing 50 intervals per decade, cosine bin spacing 0.01
- **Case D:** Cross section spacing 100 intervals per decade, cosine bin spacing 0.005
- **Case E:** Cross section spacing 200 intervals per decade, cosine bin spacing 0.01

The results shown in Tables II(a-c) depict the error relative to Case E, with 40 bins and 1.2 billion neutron histories. It is apparent that by comparing Case A, Case B,

and Case D that changing the angular spacing used to generate the double differential cross section in JANIS has little effect on the results. Comparing Case A, Case C and Case E we find that the improving the energy grid causes the integrated P1 value in Fe^{56} to vary of the order of 2%, while both Pu^{239} and Pu^{240} are insensitive to changes in energy grid, likely owing to the previously discussed smoothness of the high energy cross sections. It is clear also that the table varies more between the rows, corresponding to the options used in the computation of the sensitivity coefficient, which will be explored in the next section.

A general conclusion is that the results are not very sensitivity to fidelity of the cross section tabulation used in JANIS, although in this work even the coarse grids had a reasonably high number of data points.

Table I: Energy and Angular Spacing of tabulated elastic scattering double differential cross sections

	A	B	C	D	E
Energy(MeV)	100	100	50	100	200
Angular	0,01	0,02	0,01	0,005	0,01

Table IIa: Percent error due to double differential cross section energy/angle discretization, Fe^{56}

Fe^{56}	A	B	C	D	E
MCNP					
16 bins	-1,7	-1,7	0,1	-1,7	-2,3
20 bins	0,3	0,3	2,1	0,3	-0,4
24 bins	0,5	0,5	2,3	0,5	-0,1
24 bins*	-0,8	-0,8	1,0	-0,8	-1,3
28 bins	0,6	0,6	2,5	0,6	0,0
32 bins	0,6	0,6	2,5	0,6	0,0
36 bins	0,6	0,6	2,5	0,6	0,0
40 bins	0,6	0,6	2,5	0,6	0,0

*non-uniform spacing of grid

Table IIb: Percent error due to double differential cross section energy/angle discretization, Pu^{239}

Pu^{239}	A	B	C	D	E
16 bins	-4,9	-4,9	-4,9	-4,9	-4,9
20 bins	-2,0	-2,0	-2,0	-2,0	-2,0
24 bins	-0,3	-0,3	-0,3	-0,3	-0,3
24 bins*	-3,4	-3,4	-3,4	-3,4	-3,4
28 bins	0,2	0,2	0,2	0,2	0,2
32 bins	-0,2	-0,2	-0,2	-0,2	-0,2
36 bins	-0,2	-0,2	-0,2	-0,2	-0,2
40 bins	0,0	0,0	0,0	0,0	0,0

*non-uniform spacing of grid

Table IIc: Percent error due to double differential cross section energy/angle discretization, Pu^{240}

Pu^{240}	A	B	C	D	E
16 bins	-3,4	-3,4	-3,4	-3,4	-3,4
20 bins	-4,7	-4,7	-4,7	-4,7	-4,7
24 bins	-2,0	-2,0	-2,0	-2,0	-2,0
24 bins*	-2,7	-2,7	-2,7	-2,7	-2,7
28 bins	0,0	0,0	0,0	0,0	0,0
32 bins	-0,7	-0,7	-0,7	-0,7	-0,7
36 bins	-0,7	-0,7	-0,7	-0,7	-0,7
40 bins	0,0	0,0	0,0	0,0	0,0

*non-uniform spacing of grid

B. Options used in MCNP

The first MCNP option tested was the impact of the number of neutron histories on the energy integrated P1 coefficients to assess the impact of Monte Carlo statistics on the process. Table III shows that the error above 40 M histories is within 8% for both Fe^{56} and Pu^{239}, while the error is higher for Pu^{240} owing to the smaller absolute value of the coefficient. Note that 1.0E-2 %dk/%dP1 = 10 pcm per percent change in P1.

Table III: Impact of the number of histories on the energy integrated P1 sensitivity coefficient. (%dk/%dP1)

Histories (Million)	Fe^{56}	Pu^{239}	Pu^{240}
10	-7,28E-02	-8,86E-02	-7,25E-04
40	-7,47E-02	-6,56E-02	-1,38E-03
80	-7,54E-02	-6,67E-02	-8,96E-04
160	-7,60E-02	-6,07E-02	-1,44E-03
320	-7,63E-02	-6,21E-02	-1,07E-03
640	-7,59E-02	-6,14E-02	-1,11E-03
1280	-7,58E-02	-6,21E-02	-1,28E-03

Tables IV(a-c) show comparisons of the percent of the value of the integrated sensitivity coefficient varying both the number of neutron histories and the number of cosine bins; all results are relative to 1280 Million neutrons histories with 40 cosine bins. When interpreting the results it is important to note that the random seed was not varied so that the neutron flux is the same between the columns in the table, thus one is seeing only the impact of the discretization of the tallies leading to a lower statistical uncertainty than would be expected otherwise.

It is seen that Fe^{56} results vary only by a few percent across different numbers of cosine bins and are also quite stable. Conversely for Pu^{239} the results for 10 Million histories have a large amount of numerical noise, nearly 40%, which is likely unacceptable for many applications. Interestingly for Pu^{239} when using a lower number of histories it is often more accurate to use coarser cosine bins, while for a larger number of histories one can move to finer bins to compute the sensitivity coefficients. In the case of Pu^{240} the statistical noise dominates owing to the magnitude

of the coefficient, while relative to this, the number of cosine bins used to compute the sensitivity coefficient has little effect.

Table IVa: Percent error of the P1 coefficient vs the number of cosine bins used in the elastic scattering sensitivity coefficient in MCNP, Fe^{56}

Fe^{56}	16 bins	20 bins	24 bins	24 bins*	28 bins	32 bins	36 bins	40 bins
10M	-6,5	-5,2	-4,7	-6,2	-4,6	-4,5	-4,5	-4,4
40M	-4,1	-2,5	-2,3	-3,7	-2,2	-2,3	-2,2	-2,2
80M	-3,2	-1,3	-1,0	-2,4	-1,0	-1,0	-0,9	-0,9
160M	-2,5	-0,5	-0,3	-1,5	-0,2	-0,2	-0,1	-0,1
320M	-2,0	0,0	0,3	-1,2	0,4	0,4	0,5	0,5
640M	-2,6	-0,6	-0,2	-1,8	-0,1	0,0	0,0	0,0
1280M	-2,7	-0,6	-0,3	-1,8	-0,1	-0,1	0,0	0,0

Table IVb: Percent error of the P1 coefficient vs the number of cosine bins used in the elastic scattering sensitivity coefficient in MCNP, Pu^{239}

Pu^{239}	16 bins	20 bins	24 bins	24 bins*	28 bins	32 bins	36 bins	40 bins
10M	37,0	36,7	39,1	35,3	37,9	36,5	37,1	37,0
40M	1,4	3,2	6,6	5,8	7,0	6,7	6,8	6,7
80M	3,2	5,0	7,1	3,9	8,4	7,1	7,4	7,4
160M	-6,0	-3,3	-1,6	-4,7	-1,1	-1,5	-1,5	-1,4
320M	-4,0	-1,2	-0,3	-3,1	0,1	-0,3	-0,5	-0,4
640M	-5,0	-2,4	-1,4	-3,7	-1,2	-1,2	-1,4	-1,3
1280M	-3,9	-1,0	-0,1	-2,4	-0,1	0,0	0,0	0,0

Table IVc: Percent error of the P1 coefficient vs the number of cosine bins used in the elastic scattering sensitivity coefficient in MCNP, Pu^{240}

Pu^{240}	16 bins	20 bins	24 bins	24 bins*	28 bins	32 bins	36 bins	40 bins
10M	-44,3	-52,4	-63,3	-45,8	-66,1	-58,9	-58,6	-58,7
40M	5,8	13,5	12,4	19,5	12,6	16,4	19,5	19,6
80M	-31,1	-32,2	-33,8	-28,4	-34,5	-33,6	-31,3	-30,6
160M	10,4	9,4	12,2	11,4	14,3	13,7	13,7	14,3
320M	-17,5	-15,4	-10,8	-12,6	-9,7	-9,4	-10,4	-10,4
640M	-15,0	-13,1	-10,4	-15,0	-11,0	-11,1	-11,1	-11,2
1280M	-1,8	0,0	0,4	-3,5	-0,3	-0,1	0,0	0,0

The general conclusion from this section is that for coefficients of the order of tens of pcm per percent change in P1, at least 40 Million histories should be run, while for coefficients around a few pcm per percent change in P1 it appears that nearly a billion histories are required. Unless a large number of histories are run, little is gained by increasing the spacing of the cosine bins used to tally the sensitivity coefficient, in fact it may lead to larger numerical errors.

C. Options used in Integration/Python Script

The python script computes equation (1). To do so it computes the average change in cross sections on the same grid that the sensitivity coefficients are computed on. Two options were tested, the first is the order of the bivariate spline used to fit the double differential cross section, where the order is given by the integer assigned to kx and ky. The second option tested was the number of intervals used to perform the integration of the spline, given by the limit option, with the integer number indicating the number of subintervals used.

Tables V(a-c) show the results of varying these options. Note that 16 cosine bins were used to compute the sensitivity profiles, and Case A was used to generate the double differential cross sections.

The general conclusion is that the order of the spline and the integration options have a negligible influence on the energy integrated value of the coefficient.

Table Va: Percent error of the P1 coefficient vs the order of the bivariate spline fit and the number of subintervals used in the integration for Fe^{56}

Fe^{56}	kx=ky=1	kx=ky=2	kx=ky=3	Lim 50	Lim 100	Lim 200
640M	0.3	0.1	0.1	0.1	0.1	0.1
1280M	0.2	0.0	0.0	0.0	0.0	0.0

Table Vb: Percent error of the P1 coefficient vs the order of the bivariate spline fit and the number of subintervals used in the integration for Pu^{239}

Pu^{239}	kx=ky=1	kx=ky=2	kx=ky=3	Lim 50	Lim 100	Lim 200
640M	-1.2	-1.2	-1.2	-1.2	-1.2	-.12
1280M	0.0	0.0	0.0	0.0	0.0	0.0

Table Vc: Percent error of the P1 coefficient vs the order of the bivariate spline fit and the number of subintervals used in the integration for Pu^{240}

Pu^{240}	kx=ky=1	kx=ky=2	kx=ky=3	Lim 50	Lim 100	Lim 200
640M	-13.5	-13.5	-13.5	-13.5	-13.5	-13.5
1280M	0.0	0.0	0.0	0.0	0.0	0.0

D. Options Used for DICE Sensitivity Coefficients

All of the results currently in DICE were computed with the following parameters,

Cross Sections/JANIS:

- 100 bins per decade energy spacing
- 200 cosine bins

MCNP:

- 100 Million neutron histories
- SCALE 238 energy group structure

- 16 cosine bins

Integration/Python:

- Quadratic Spline fit
- 100 intervals per division

As the DICE values, which were chosen prior to this work based on scoping studies with bare plutonium spheres, use 100 M and 16 bins, the results for coefficients of the order of 10s of pcm per percent change in P1 the error of the order of 5%, while for coefficients of the order of a few pcm per percent change in P1, the error can be an order of magnitude higher owing to the statistical convergence.

This error was deemed acceptable for the data used to populate and search a database, as always, users should be aware of the accuracy when applying the data in other applications.

III. RESULTS

1. Overview of DICE P1 elastic sensitivity data

The intention of the work has been to provide reliable data for a tool to assist nuclear data validators to select suitable benchmarks for data testing. In late 2016 the computed P1 elastic data were added into DICE and the capabilities and details are described here.

An example screenshot of how to use DICE to perform a simple search for P1 elastic angular scattering sensitivities is shown in Fig. 3. The user has the option to select to search for sensitivity coefficients in the left most column, and then subsequently select 'elastic-P1' in the reaction column. Further refinement is performed by selecting a particular isotope, or selecting to return only coefficients whose value is within a specified numerical range. This capability can be combined using Boolean logic with the other search criteria available in DICE.

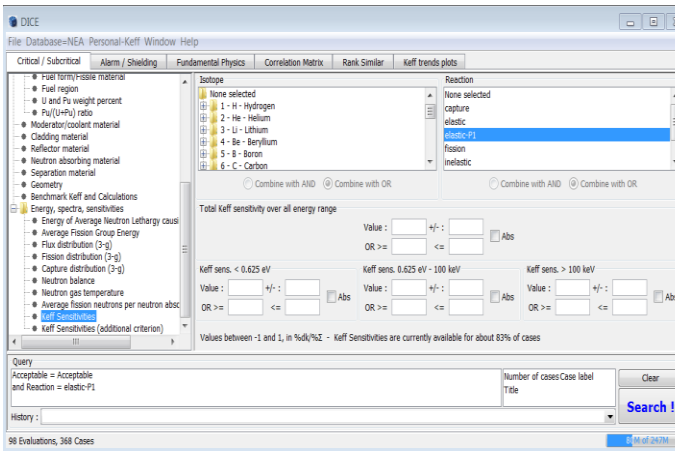

Fig. 3. Screen shot of DICE illustrating how to search for benchmarks based on P1 elastic scattering sensitivity

The search returns a table containing benchmarks with P1 data and that match the other search criteria. In Fig. 4 an example search to returning the P1 elastic scattering sensitivity coefficient for all benchmarks with U^{238} P1 data is shown. Users can sort the table by any of the column values. In Fig. 4 the values are sorted so that the benchmark with the most negative value for P1 is the first row, and has a value of 141.7 pcm per-percent change in P1.

Case identification	Isotope	Reaction	Total Keff sensitivity (0 - 20 MeV) (%dk/%Σ)
PU-MET-FAST-006-001	U238	elastic-P1	-0.1417
PU-MET-FAST-041-001	U238	elastic-P1	-0.1295
HEU-MET-FAST-003-003	U238	elastic-P1	-0.1216
HEU-MET-FAST-003-004	U238	elastic-P1	-0.1209
PU-MET-FAST-010-001	U238	elastic-P1	-0.119
HEU-MET-FAST-003-002	U238	elastic-P1	-0.1166
HEU-MET-FAST-003-007	U238	elastic-P1	-0.1161
HEU-MET-FAST-028-001	U238	elastic-P1	-0.1159
HEU-MET-FAST-032-001	U238	elastic-P1	-0.1146
HEU-MET-FAST-003-006	U238	elastic-P1	-0.1138
HEU-MET-FAST-032-002	U238	elastic-P1	-0.1135
PU-MET-FAST-012-001	U238	elastic-P1	-0.1082
HEU-MET-FAST-014-001	U238	elastic-P1	-0.1048
HEU-MET-FAST-003-001	U238	elastic-P1	-0.1033
HEU-MET-FAST-032-003	U238	elastic-P1	-0.0985
HEU-MET-FAST-055-001	U238	elastic-P1	-0.0711
HEU-MET-FAST-030-001	U238	elastic-P1	-0.0708
HEU-MET-FAST-038-001	U238	elastic-P1	-0.0684
HEU-MET-FAST-052-001	U238	elastic-P1	-0.0635
HEU-MET-FAST-032-004	U238	elastic-P1	-0.06
IEU-MET-FAST-018-002	U238	elastic-P1	-0.0367

Fig. 4. Screen shot of DICE results showing the benchmarks with the highest integrated P1 sensitivity coefficients for U^{238}

All P1 data has been collapsed and stored in three energy groups, like all other sensitivity coefficient data. However, since the values below 0.052 MeV were at the level of noise, all data below this point has been set to zero, thus no benchmarks have thermal P1 data, and the intermediate energy range values are also truncated.

If the users require more detail about the energy group structure of the sensitivity profile, the 'sensitivity plots button' allows access to the plots of P1 elastic as shown in Fig. 5, as well as the capability to access the data in tabular format, simplifying data extraction. Users can access the values of the coefficient vs energy in the energy group structure of the computation, or the values can be collapsed within the tool to another energy group structure.

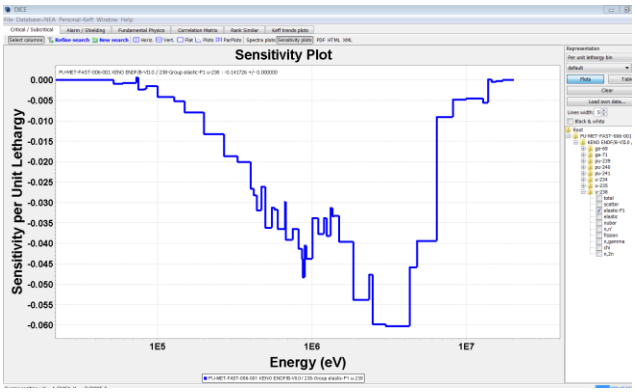

Fig. 5. Screen shot of DICE illustrating how to search for benchmarks based on P1 elastic scattering sensitivity

2. Example of Uncertainty Propagation

In order to provide the reader with some insight into the magnitude of the importance of the angular data we have briefly perform some sample uncertainty propagation. Many of the libraries, such as ENDF/B-VII.0 used for most calculations in this paper, do not contain an MF34 which is the file used to store the uncertainty in P1. However JENDL4.0 contains a fair amount of covariance data, and while combining this data with the ENDF/B-VII.0 P1 data is not rigorous, the intent here is to give an approximate value that one would obtain when performing uncertainty analysis.

Fig. 6 shows the uncertainty in P1 as a function of energy as well as the P1 sensitivity coefficients. The plot shows that energies with large uncertainties in P1, typically have small P1 values, and small P1 sensitivity coefficients. There tends to be a few key energy bins that contribute most to the total uncertainty due to angular scattering.

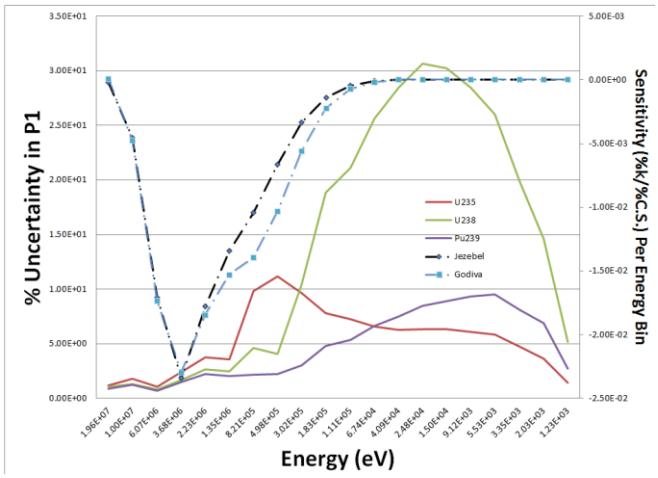

Fig. 6. Uncertainty in JENDL mu-bar data and the sensitivity of select integral benchmarks. Note: mu-bar was used here only used for illustrative purposes, the full P1 covariance matrix was used in uncertainty propagation

Using DICE benchmarks that exhibited the largest sensitivity values were selected in order to perform sample uncertainty propagation for these benchmarks. The top 3 benchmarks in terms of P1 sensitivity for Fe^{56}, U^{235}, U^{238}, and Pu^{239} were chosen and the sensitivity coefficient was multiplied by the P1 covariance matrix. The results are shown in Table VI. Note that although the ENDF/B format allows for correlations between Legendre polynomials, all of the MF34 data for the isotopes selected consisted of solely a covariance matrix of P1 at different energy points.

Table VI: Estimate of the uncertainty in integral benchmarks due to uncertainty in P1 data.

Benchmark	Isotope	Uncertainty (pcm)
PMF026-001	Fe^{56}	326
PMF015-001	Fe^{56}	326
PMF032-001	Fe^{56}	255
HMF001-001	U^{235}	463
HMF007-019	U^{235}	434
HMF043-001	U^{235}	406
PMF006-001	U^{238}	322
PMF041-001	U^{238}	296
HMF003-003	U^{238}	305
PMF001-001	Pu^{239}	161
PMF022-001	Pu^{239}	156
PMF025-001	Pu^{239}	134

From Table VI, it is clear that P1 uncertainty is a non-negligible term that should be considered when performing uncertainty analysis and quantification. This statement appears to be particularly true for those benchmarks sensitive to P1-elastic U^{235} and/or U^{238}. Hopefully the data in DICE will help stimulate consideration of the impact of P1 uncertainties.

IV. CONCLUSIONS

A large complement of P1 Sensitivity data for PMF, HMF and HST ICSBEP benchmarks is now distributed with the software DICE. Users can easily search for the most sensitive benchmarks. Preliminary estimates of the amount of uncertainty from P1 are of nearly 500 pcm for benchmarks which exhibit high sensitivity to the U^{235} elastic scattering P1 value. The tools to perform such analysis are openly available at https://www.oecd-nea.org/science/wpncs/icsbep/dice.html.

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