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ARTICLE

Benchmark test of JENDL-4.0 with TOF experiments at Osaka Univ./OKTAVIAN

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JENDL-4.0, the major revised version of Japanese Evaluated Nuclear Data Library (JENDL), was released in May 2010. In order to validate JENDL-4.0, we analyzed TOF experiments with DT neutrons at OKTAVIAN in Osaka University with JENDL-4.0 and MCNP5.14. For comparison, the older version JENDL-3.3 and other recent nuclear data libraries ENDF/B-VII.0 and JEFF-3.1 were also used. As a result, the followings were found out: (1) Si, As, Se, Mo and W : the calculation results with JENDL-4.0 agreed with the measured ones better than those with JENDL-3.3, (2) Cr, Mn and Nb : the calculation results with JENDL-4.0 were partially better and partially worse than those with JENDL-3.3.

Keywords: JENDL-4.0; benchmark test; MCNP; OKTAVIAN; TOF experiment; DT neutron

1. Introduction

JENDL-4.0 [1], the major revised version of Japanese Evaluated Nuclear Data Library (JENDL), was released in May, 2010. It is important to validate JENDL-4.0 through analyses of integral benchmark experiments. So far we benchmarked it through the benchmark experiments carried out at the Fusion Neutronics Source (FNS) facility in Japan Atomic Energy Agency (JAEA) [2, 3] on beryllium, carbon, silicon, vanadium, iron, copper, tungsten and lead.

From 1984 to 1988, sphere pile integral benchmark experiments were carried out with DT neutrons of OKTAVIAN in Osaka University [4] on LiF, CF_2, Al, Si, Ti, Cr, Mn, Co, Cu, As, Se, Zr, Nb, Mo and W. Thus we analyze these experiments with JENDL-4.0 as one of benchmark tests of JENDL-4.0.

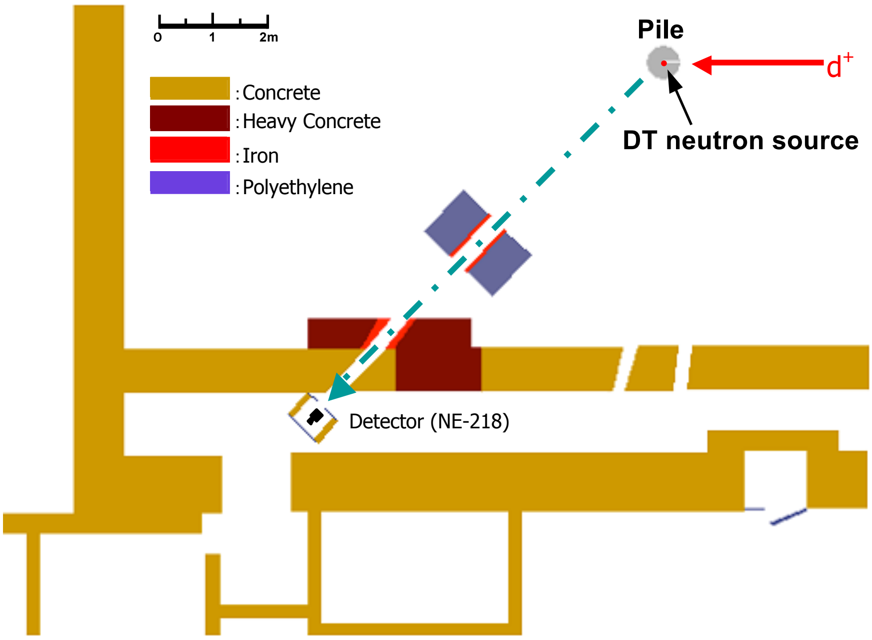

Figure 1. Experimental arrangement.

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2. Overview of TOF experiments at OKTAVIAN

Leakage neutron spectra from spherical piles were measured with the time-of flight (TOF) technique at the DT neutron source facility OKTAVIAN in Osaka University. The piles were made by filling spherical vessels with sample powder or flakes of LiF, CF_2, Al, Si, Ti, Cr, Mn, Co, Cu, As, Se, Zr, Nb, Mo and W. The material densities and outer diameters of the vessels are summarized in **Table 1**. DT neutrons were produced by bombarding a 370 GBq tritium target placed at the center of the pile with 250 keV deuteron beam. A cylindrical liquid organic scintillator NE-218 was used as a neutron detector, which was located at about 11 m from the tritium target and 55 deg. with respect to the deuteron beam axis, surrounded by concrete and heavy concrete. A pre-collimator made of polyethylene-iron multi-layers was set between the pile and the detector in order to reduce the background neutrons. The experimental arrangement is shown in **Figure 1**.

Table 1. Material density and outer diameter of vessel.

Material	Apparent density (g/cm^3)	Outer diameter of vessel (cm)
LiF	1.79	61
CF_2	1.30	40
Al	1.22	40
Si	1.29	60
Ti	1.54	40
Cr	3.72	40
Mn	4.37	61
Co	1.94	40
Cu	6.23	61
As	3.09	40
Se	2.29	40
Zr	2.84	61
Nb	4.39	28
Mo	2.15	61
W	4.43	40

3. Analysis

The Monte Carlo code MCNP-5.14 [5] and the official ACE file FSXLIB-J40 of JENDL-4.0 were used for the analysis. Calculations with the ACE files of the following nuclear data libraries were also carried out for comparison.
-JENDL-3.3 (ACE file : FSXLIB-J33) [6]
-ENDF/B-VII.0 (ACE file : endf70 in MCNP Data) [7]
-JEFF-3.1 (ACE file : MCJEFF3.1) [8]
Experiments for lithium fluoride and aluminum piles were not analyzed in this work because the data of these nuclei were not revised in JENDL-4.0.

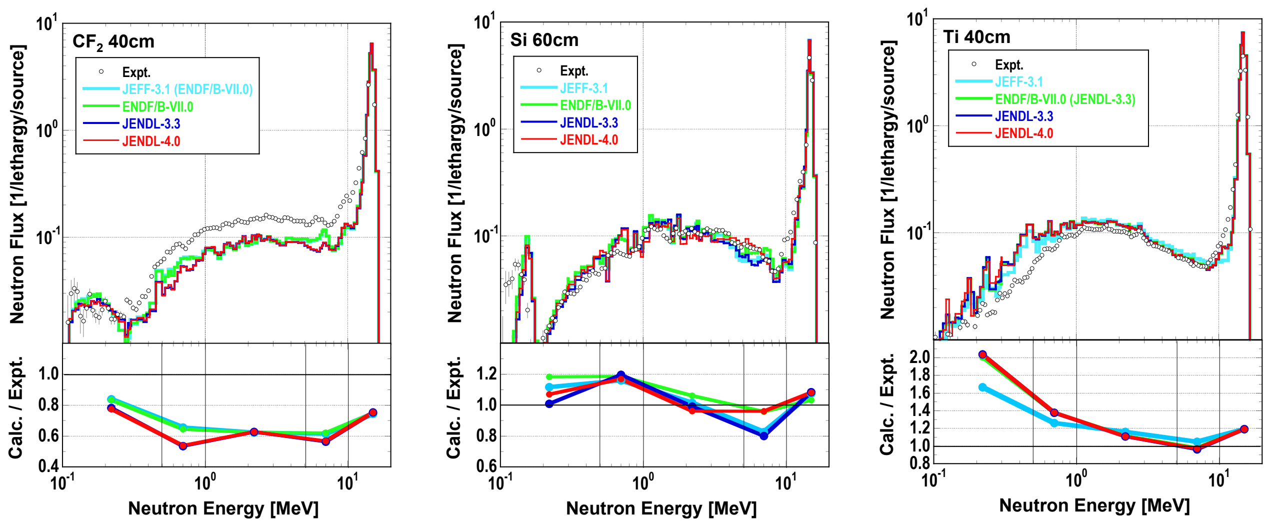
4. Results and discussion

4.1. CF_2 sphere

The measured and calculated neutron spectra are shown in **Figure 2(a)** with ratios of calculation to experiment (C/E) for each specific energy region of 0.1-0.5 MeV, 0.5-1 MeV, 1-5 MeV, 5-10 MeV and > 10 MeV. There is no difference between the calculation results with JENDL-3.3 and JENDL-4.0, though the capture cross-section data of carbon are modified in JENDL-4.0. All the calculation results underestimated the measured one by ~ 40 %. The measured neutron spectrum may have some problems.

4.2. Si sphere

The Si isotope data in JENDL-4.0 are newly evaluated by using the TNG code [9]. The resolved resonance parameters are taken from ENDF/B-VII.0. Thus there are many modifications in the Si isotope data of JENDL-4.0. **Figure 2(b)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The underestimation around 8 MeV in the calculation result with JENDL-3.3 is improved in that with JENDL-4.0, though the difference between the calculation results with JENDL-3.3 and JENDL-4.0 was



(a) CF_2 sphere (b) Si sphere (c) Ti sphere

Figure 2. Measured and calculated leakage neutron spectra from sphere of (a) CF_2, (b) Si and (c) Ti.

small in the SiC in-situ experiment at JAEA/FNS [3]. The calculation result with JENDL-4.0 is better than those with ENDF/B-VII.0 and JEFF-3.1.

4.3. Ti sphere

The resolved resonance parameters of the titanium isotopes are modified in JENDL-4.0. **Figure 2(c)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The calculation result with JENDL-4.0 is almost the same as that with JENDL-3.3. The overestimation below 1 MeV is not improved.

4.4. Cr sphere

The data above the resolved resonance region of the chromium isotopes in JENDL-4.0 are re-evaluated with the CCONE code [10]. **Figure 3(a)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The calculation result with JENDL-4.0 tends to overestimate the measured one more than that with JENDL-3.3, particularly around 8 MeV. The chromium data in JENDL-3.3 are the best.

4.5. Mn sphere

The resolved resonance parameters and the elastic scattering cross section data of ^{55}Mn are modified in JENDL-4.0. Moreover the unresolved resonance data are newly added in JENDL-4.0. **Figure 3(b)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The calculation result with JENDL-4.0 overestimates the measured one below 1 MeV more than that with JENDL-3.3. This is considered to be due to the unresolved resonance data newly added in JENDL-4.0 [11].

4.6. Co sphere

Figure 3(c) shows the measured and calculated neutron spectra with C/Es for each specific energy region. The calculation result with JENDL-4.0 is almost the same as that with JENDL-3.3. The underestimation

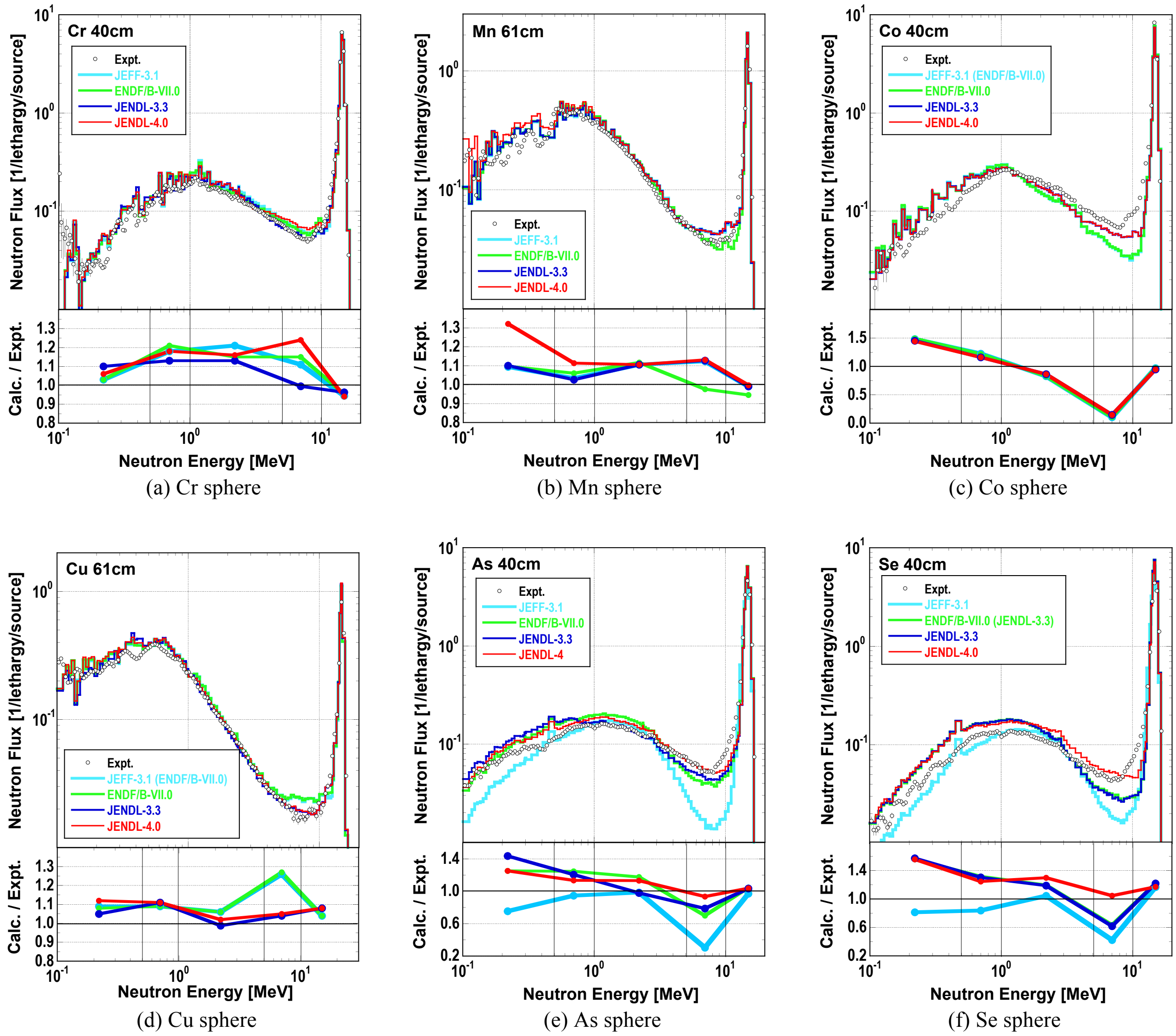


Figure 3. Measured and calculated leakage neutron spectra from sphere of (a) Cr, (b) Mn, (c) Co, (d) Cu, (e) As and (f) Se.

from a few MeV to 10 MeV and overestimation below 1 MeV are not improved at all. Those with ENDF/B-VII.0 and JEFF-3.1 are slightly worse than those with JENDL-3.3 and JENDL-4.0.

4.7. Cu sphere

The cross section and angular distribution data of the elastic scattering in ^{63}Cu and ^{65}Cu are modified in JENDL-4.0. The measured and calculated neutron spectra are shown in **Figure 3(d)** with C/Es for each specific energy region. The calculation result with JENDL-4.0 overestimates the measured one slightly compared to that with JENDL-3.3, though it is better than those with ENDF/B-VII.0 and JEFF-3.1.

4.8. As sphere

All the data of ^{75}As in JENDL-4.0 are re-evaluated with the POD code [12]. **Figure 3(e)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The underestimation from 3 MeV to 10 MeV and overestimation below 1 MeV in the calculation result with JENDL-3.3 are improved in that with JENDL-4.0, while the calculation result with JENDL-4.0 overestimates the measured neutron flux from 1 MeV to 3 MeV. Generally speaking, the calculation result with JENDL-4.0 is the best.

4.9. Se sphere

Most data of the selenium isotopes in JENDL-4.0 are re-evaluated with the POD code. **Figure 3(f)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The underestimation of the neutron flux from 3 MeV to 10 MeV is improved in the calculation result with JENDL-4.0. The overestimation below 1 MeV is not improved even in the calculation result with JENDL-4.0.

4.10. Zr sphere

The resonance parameters and the capture cross-section data of the zirconium isotopes are modified in JENDL-4.0. **Figure 4(a)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The calculation result with JENDL-4.0 is almost the same as that with JENDL-3.3.

4.11. Nb sphere

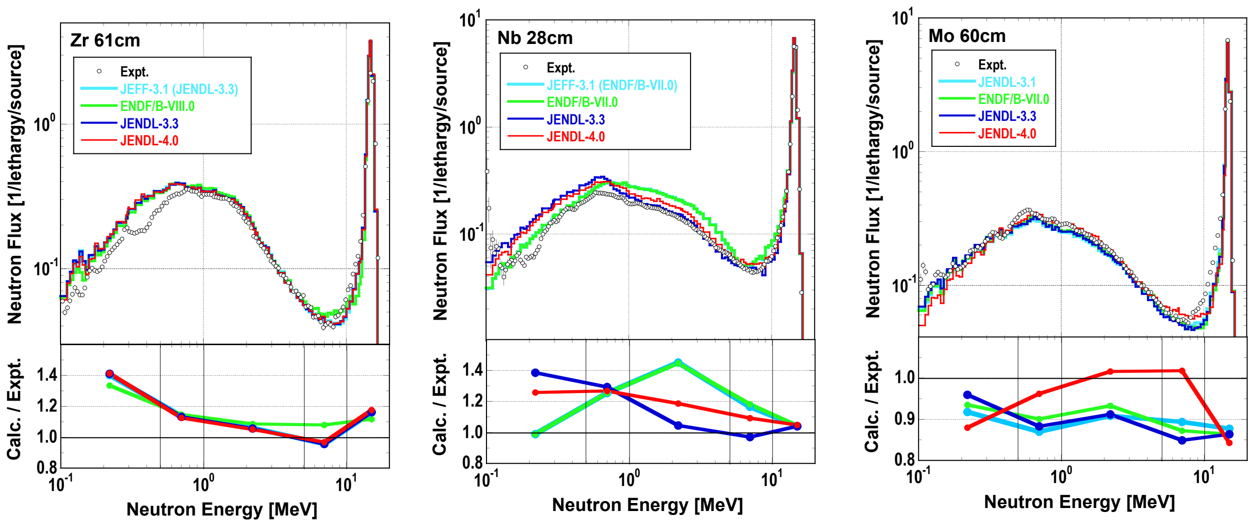
The resonance parameters and the energy-angle distribution data of ^{93}Nb are mainly modified in JENDL-4.0. **Figure 4(b)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The calculation result with JENDL-4.0 overestimates the measured neutron flux from 0.7 MeV to 10 MeV, while that with JENDL-3.3 agrees with the measured neutron flux well. The overestimation below 1 MeV is slightly improved in the calculation result with JENDL-4.0. The calculation result with ENDF/B-VII.0 (JEFF-3.1) overestimates the measured neutron flux from 0.6 MeV to 10 MeV more, though it agrees with the measured neutron flux below 0.6 MeV.

4.12. Mo sphere

Most data of the molybdenum isotopes in JENDL-4.0 are re-evaluated with the POD code. **Figure 4(c)** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The calculation result with JENDL-4.0 agrees with the measured neutron flux from 0.6 MeV to 5 MeV better than those with JENDL-3.3, ENDF/B-VII.0 and JEFF-3.1, while it slightly underestimates the measured neutron flux below 0.5 MeV.

4.13. W sphere

Most data of the tungsten isotopes in JENDL-4.0 are



(a) Zr sphere (b) Nb sphere (c) Mo sphere

Figure 4. Measured and calculated leakage neutron spectra from sphere of (a) Zr, (b) Nb and (c) Mo.

re-evaluated with the CCONE code. **Figure 5** shows the measured and calculated neutron spectra with C/Es for each specific energy region. The calculation result with JENDL-4.0 agrees with the measured one better than that with JENDL-3.3 and it is almost the same as that with ENDF/B-VII.0.

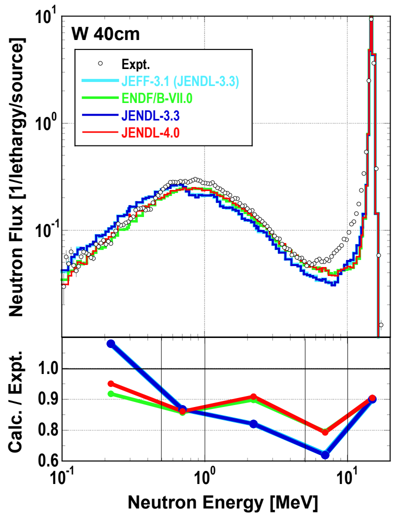


Figure 5. Measured and calculated leakage neutron spectra from W sphere.

5. Conclusion

We benchmarked JENDL-4.0 with the TOF experiments at Osaka University / OKTAVIAN. The followings are found out:

1) Si, As, Se, Mo and W spheres : the calculation results with JENDL-4.0 agree with the measured ones better than those with JENDL-3.3.
2) CF_2, Ti, Co, Cu and Zr spheres : the calculation results with JENDL-4.0 are comparable to those with JENDL-3.3.
3) Cr, Mn and Nb spheres : the calculation results with JENDL-4.0 are partially better and partially worse than those with JENDL-3.3.

It is generally concluded that JENDL-4.0 is improved compared to JENDL-3.3. Next we will investigate which reactions in JENDL-4.0 contribute to the improvement or deterioration in detail.

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