PHYSOR 2012 – Advances in Reactor Physics – Linking Research, Industry, and Education
Knoxville, Tennessee, USA, April 15-20, 2012, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2012)

CASMO5 JENDL-4.0 and ENDF/B-VII.1beta4 Libraries

Joel Rhodes, Nicholas Gheorghiu, and Rodolfo Ferrer
Studsvik Scandpower, Inc.
504 Shoup Ave., Suite 201, Idaho Falls, ID 83402
joel.rhodes@studsvik.com, nicholas.gheorghiu@studsvik.com, rodolfo.ferrer@studsvik.com

ABSTRACT

This paper details the generation of neutron data libraries for the CASMO5 lattice physics code based on the recently released JENDL-4.0 and ENDF/B-VII.1beta4 nuclear data evaluations. This data represents state-of-the-art nuclear data for late-2011. The key features of the new evaluations are briefly described along with the procedure for processing of this data into CASMO5, 586-energy group neutron data libraries. Finally some CASMO5 results for standard UO2 and MOX critical experiments for the two new libraries and the current ENDF/B-VII.0 CASMO5 library are presented including the B&W 1810 series, DIMPLE S06A, S06B, TCA reflector criticals with iron plates and the PNL-30-35 MOX criticals. The results show that CASMO5 with the new libraries is performing well for these criticals with a very slight edge in results to the JENDL-4.0 nuclear data evaluation over the ENDF/B-VII.1beta4 evaluation. Work is currently underway to generate a CASMO5 library based on the final ENDF/B-VII.R1 evaluation released Dec. 22, 2011.

Key Words: CASMO, JENDL-4.0, ENDF/B-VII.R1, LATTICE CODE, CRITICALS

1. INTRODUCTION

As the underlying neutron data library is extremely important to a lattice physics code, the recent release of two updated nuclear evaluations (JENDL-4.0 and ENDF/B-VII.1beta4) provides the opportunity to generate neutron data libraries for CASMO-5 based upon the latest available data. Nuclear data evaluations are a large complex collection of data (more than just cross sections) released every few years and only after great effort has been expended to ensure that the best available data is being used. There has been great progress in nuclear data evaluations in the last decade as evaluations become more complete, i.e., include more nuclides, and become more refined in their fundamental data.

At the time of lattice code library generation, there is incentive to use the best available data as improvements in the underlying basic nuclear data can provide a direct path to improving results and can help reduce or remove biases in applications downstream from the lattice code, e.g. 3D nodal simulators. However, this is not always the case and it is only with careful testing and validation in the actual end use applications that an evaluation can be regarded to be an improvement. The processing of multigroup libraries appears to be done less frequently than in the past such that each new evaluation poses new challenges and much of the testing appears to be aimed at continuous energy applications. This paper details some of the practical experience gained with these new evaluations. This paper examines the process of generating 586 group neutron data libraries for the CASMO5 lattice physics code based on the very recently released JENDL-4.0 (May 2010) and ENDF/B-VII.1beta4 (Sept. 2011) nuclear data evaluations and provides some comparisons for experimental criticals with the two libraries based on state-of-art nuclear data.

2. CASMO5 LATTICE PHYSICS CODE AND NEUTRON LIBRARY

CASMO5 [1] is Studsvik's next generation Light Water Reactor (LWR) lattice physics code specifically designed to handle next generation heterogeneous fuel designs, advanced absorbers and control rods and extended cycle lengths for both PWRs and BWRs.

CASMO5 shares some common methodology heritage with CASMO-4 [2] but also has many advanced numerical models/features which are not part of the standard CASMO-4 methodology:

- 1D collision probability based pincell calculations performed in the library group structure (586 energy groups for CASMO5).
- 2D Method of Characteristics (MoC) based transport calculation (performed in 19 groups for UO2 lattices and 35 groups for MOX lattices) with both flat source and linear source options available.
- Equivalence theorem based resonance calculation with optimum two-term rational expression and a characteristics-based Dancoff factor calculation (square geometry with reflective boundary conditions).
- Monte Carlo based resonance upscatter model to overcome deficiencies of an asymptotic scattering kernel used in NJOY [3].
- Optimum 3 polar angle numerical quadrature in the 2D transport solution (T-Y quadrature) [4].
- Quadratic Gd-depletion model [5].
- Greatly extended depletion chains for both actinides and fission products (with no lumped fission product utilized).
- Explicit energy release per fission model based on problem specific capture rates [6].
- Automated case matrix generation capability for both SIMULATE-3 (two-group) and SIMULATE5 (multigroup) library generation.
- Predictor/corrector based depletion (with optional azimuthal depletion).
- Optional 18 group gamma calculation (with ENDF/B-VII.0 based gamma data).

The CASMO5 neutron data library is a 586 energy group library and has 128 fast groups (20 MeV to 9.118 keV), 41 resonance groups with shielded data (9.118 keV to 10 eV), 375 narrow groups (10 eV to 0.625 eV) and 42 thermal groups (below 0.625 eV). This energy structure allows the ^{238}U resonance at 6.67 eV, the ^{240}Pu resonance at 1.06 eV, and other large resonances in the low eV range to be explicitly treated and reduce overall reliance on approximate resonance self-shielding models in this energy range. The current CASMO5 production library is primarily ENDF/B-VII.0 (E7R0) based.

There are several major data components that comprise a CASMO5 neutron data library:

- Multigroup microscopic cross section data for: σ_a, σ_f, $\nu\sigma_f$, and σ_{tr} and P_0 scattering matrices
- Resonance data (shielding data tabulated at 18 background cross sections and up to 10 temperatures spanning 293K to 2700K)
- Resonance upscatter data and Goldstein-Lambda values

- Prompt and delayed neutron fission spectra
- Delayed neutron data (β's, λ's and delayed neutron emission spectra)
- Pn-scattering data (up to order 5 for nuclides where anisotropic scattering is important)
- (n,2n), (n,3n) and (n,4n) data (previous CASMO5 data libraries ignored (n,3n and n,4n)
- Fission yield and radioactive decay data and energy release per fission data

The new CASMO-5 libraries have 568 nuclides/materials with resonance data for 232 nuclides including major fission products. The two new data libraries have 59 heavy nuclides (compared to 51 for the previous CASMO5 library) as well as 252 explicit fission products (up from 234). No ad-hoc adjustment to U-238 resonance absorption was made to this library as had been necessary in the past for ENDF/B-VI data.

3. JENDL-4.0 NUCLEAR DATA EVALUATION

The JENDL-4.0 (J4.0) nuclear data evaluation [7, 8] was released in May 2010 with the goal of improving fission product and minor actinide data over the previous JENDL-3.3 evaluation. The focus on fission products and minor actinides was an attempt to improve R&D results for innovative reactors, high burn-up fuels, use of MOX fuels for current LWRs, and burn-up credit on the backend of the fuel cycle. The J4.0 evaluation contains more nuclides (406) than either ENDF/B-VII.0 (393) or JEFF-3.1.1 (381) although fewer than ENDF/B-VII.1.beta4 (418). Also of interest to LWR calculations is the use of the new Gd data [9] for Gd-157 in JENDL-4.0 where the ^{157}Gd thermal capture cross section has been reduced. Thermal cross sections for gadolinia are very important for LWR analysis. The J4.0 evaluation also includes data for ^{169}Tm and several Yb and Os isotopes. A new decay sub-library was also issued with this release.

4. ENDF/B-VII.1BETA4 NUCLEAR DATA EVALUATION

The ENDF/B-VII.R1B4 (E7R1B4) nuclear data evaluation [10] released in Sept. 2011 is intended as a follow-on to the very successful ENDF/B-VII.0 (E7R0) evaluation [11] of December 2006. The new evaluation focuses on removing known deficiencies in the E7R0 evaluation, improving evaluations for structural materials, minor actinides and providing a consistent set of covariances. Overall, about one third of the evaluations in the E7R1B4 release have been modified or replaced compared to the E7R0 evaluation. Although the ENDF/B-VII release examined in this paper is a beta release, it is expected to be quite similar to the final release and can provide some general indication of how the final E7R1 library will perform in general LWR analysis in addition to providing experience and confidence in the overall data. The ultimate goal of course is to have a production level CASMO5 library based upon the final E7R1 release and processing the beta releases as they become available can help prevent unexpected behavior at a late stage in the library development cycle. The final ENDF/B-VII.1 evaluation was released December 22, 2011 and work is currently underway is generate a CASMO5 neutron data library based on the final evaluation.

Covariance data update and additions are a large part of the E7R1 release; however, covariance data is not used by CASMO5 and is not currently of interest here. However, there are many interesting updates or replacements in this release which may potentially impact LWR lattice calculations. In particular, E7R1 contains new evaluations for ^{27}Al, ^{52}Cr, ^{53}Cr, ^{55}Mn, ^{58}Ni, ^{60}Ni, ^{78}Kr, ^{90}Zr, ^{123}Xe, ^{124}Xe, ^{180}W, ^{182}W, ^{183}W, ^{184}W, ^{186}W, ^{185}Re, ^{237}U,^{239}U, ^{240}Pu, ^{240}Am, and data taken from other evaluations for: ^{174}Hf, ^{176}Hf, ^{177}Hf, ^{178}Hf, ^{179}Hf, and ^{180}Hf (there are other nuclide updates, but these are the nuclides of particular interest to CASMO5 LWR analysis). The updated W data is of potential interest for AP1000® gray control rods [12], and the Hf data is important for BWR control rods. Although not present in E7R1B4, the final E7R1 release does include data for ^{168}Tm, ^{169}Tm, and ^{170}Tm (which play a role in the Er absorber chains). The E7R1B4 evaluation adopts the majority minor actinide data from the J4.0 evaluation which is indicative of how the various global nuclear data evaluations appear to be converging on a common data set. Although the updated ^{157}Gd data appeared in earlier beta versions of E7R1, it was not adopted in beta4 (and presumably subsequent releases). A new decay sub-library was also issued with this release. Of particular interest in the E7R1evaluation is the return to ENDF/B-VI delayed neutron data. The E7R0 delayed neutron data was not adopted in CASMO5 and more work and examination of delayed neutron data is certainly warranted. Additionally it is hoped that the 8 delayed neutron energy group structure of the JEFF-3.1.1 evaluation will not be adopted in future evaluations (primarily because of its large impact on downstream codes used by the LWR community which rely on 6 group delayed neutron data).

5. CASMO5 LIBRARY GENERATION PROCESS

Both new libraries were processed identically using a modified NJOY99.364 through a standard NJOY99 sequence of the modules: MODER, RECONR, BROADR, HEATR, PURR, THERMR and finally GROUPR. For nuclides with $S(\alpha,\beta)$ thermal scattering data, e.g. H, Be, an extra run was made with the THERMR module. After the final processing with GROUPR, a modified version of the POWR module of NJOY94.105 was run to process the data into a format that the CASMO5 library generation routines expect. After all nuclides have been processed through the NJOY system, a few nuclides are then mixed with a utility program (NJXMRG) to generate common pre-mixed materials that are available on the CASMO5 library, e.g. stainless steel, etc.

Fission yields and radioactive decay data are processed by yet another utility code (RDDFYD) which handles decisions on the type of fission yield to be placed on the library -cumulative or independent (direct) which in turn depends upon the particular depletion chains that are actually implemented in the CASMO5 code itself (only one type of yield is actually stored on the library). There is further processing of the fission yield data to handle the distinction as to whether the meta-stable states of a particular nuclide (if there are any) are explicitly represented in the CASMO depletion chains or omitted. The RDDFYD utility code also determines the incoming neutron energy dependence of the CASMO fission yield data.

Once all materials and nuclides have been generated, and the fission yield and decay data have been processed, the ASCII files are collated together by another utility program (NJXLIB) to generate a single, large (~1 gigabyte) ASCII file. The CASMO5 library is not organized by isotope, i.e., ISOTXS style, but rather by functionality to the CASMO5 program for efficiency, into seven sub-files contained with a single file, e.g. all the resonance data is grouped together, all the P_n-scattering data is grouped together, all the burnup data is grouped together, etc. This ASCII file is then converted into a binary file with another utility code (CASLIB) to form a preliminary CASMO5 library. This preliminary library is then processed through CASMO5 to perform a specialized P_n-calculation for a homogeneous composition with an imposed fission source and buckling for the generation of the transport cross section. These cross sections are then written to a file by CASMO5, and then re-read by the CASLIB utility routine which subsequently places the updated transport cross section directly on the binary CASMO5 neutron data library. For historical reasons, not all of the relevant library data is actually present on the CASMO5 library itself. Delayed neutron data (λ's, β's, and delayed neutron spectra) and prompt fission spectra are extracted from the NJOY99 files and placed directly in the CASMO5 code via data statements. Goldstein-lambda values and resonance upscatter data are generated via the Monte Carlo code MCSD and also placed into the CASMO5 code via data statements.

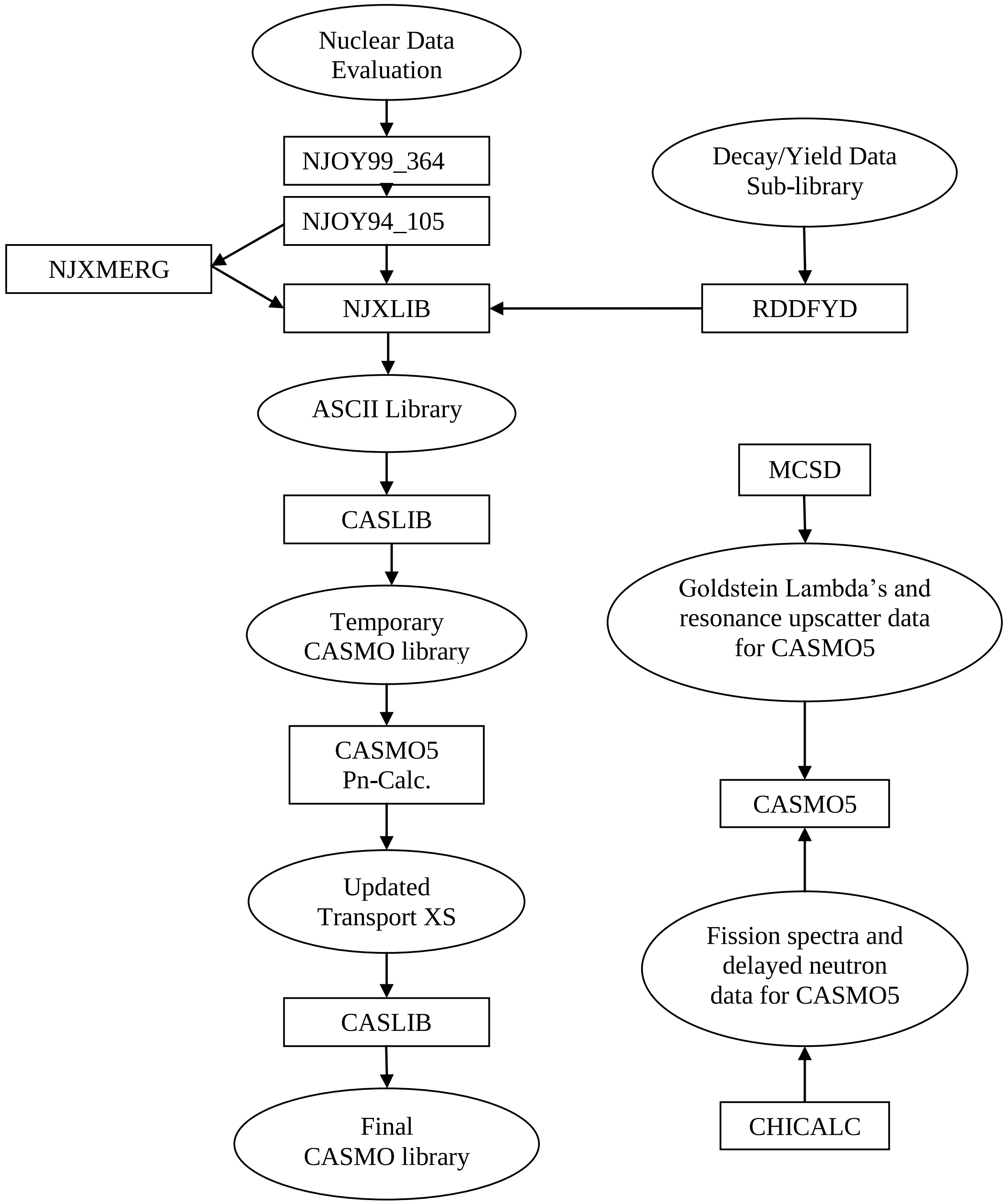

Figure 1. CASMO5 library generation process (files in ovals, codes in boxes).

In general, the processing of the E7R1B4 files for the CASMO5 library proceeded without incident except for ^{35}Cl and ^{19}F which appear to need NJOY2010 for proper processing. For those particular nuclides, the library was simply built with the appropriate ENDF/B-VII.0 data (these nuclides are relatively unimportant for CASMO5 applications).

As both nuclear data evaluations are more complete than the earlier E7R0 release that the current production CASMO5 library is based upon, there was an opportunity to further expand the actinide and fission product depletion chains for completeness, e.g., the addition of ^{234}Np and various Bk and Cf isotopes or replacement of real cross section data for nuclides that had previously been represented in CASMO5 with a simple yield/decay model (no cross section present). As the J4.0 evaluation did not contain data for ^{3}H, ^{17}O, ^{58}Co, ^{74}As, ^{125}Sn, ^{138}Ce, ^{139}Ce, ^{142}Pr, ^{165}Ho, ^{175}Lu,^{176}Lu, ^{182}Ta, ^{185}Re, ^{187}Re, ^{191}Ir, ^{193}Ir, ^{239}U, ^{240}U, and ^{243}Pu, E7R1 data were used for those particular nuclides for the J4.0 CASMO5 library (these are all relatively unimportant for most CASMO applications). Likewise, the E7R1B4 evaluation did not contain data for Yb and Os isotopes, and the J4.0 data were used for those particular nuclides on the E7R1B4 CASMO5 library. Notable data omissions from both J4.0 and E7R1B4 which are of potential use to the LWR community include ^{195}Pt (for detectors) and ^{171}Er, ^{185}W, ^{169}Yb, ^{175}Yb for burnable absorber and control rod depletion chains. In CASMO5 this data (for the absorption cross section) is taken from other evaluations, e.g. ROSFOND 2008. By making the aforementioned data substitutions to complete one common “library data set” the two libraries in consideration here have an identical structure and differ only by source of the data. By processing both data evaluations identically through the CASMO5 library generation process, results from the two data libraries can be compared directly.

6. CASMO5 RESULTS VERSUS CRITICAL EXPERIMENTS

For the following results, CASMO5 was run in 95 energy groups (to help capture high energy leakage effects), using the default quadrature in the 2D transport solution (64 azimuthal angles, 3 polar angles, and with a ray spacing of 0.05 cm). In all cases, the number of mesh (flat source regions) in the coolant regions surrounding the fuel pins was increased from the default 3 rings to a value of 5 to better calculate the steep flux gradient near the surface of pins at cold conditions. All results are P0 transport corrected unless otherwise noted in the text. As CASMO-5 is a 2D transport code, axial bucklings were part of the CASMO-5 input.

6.1 B&W 1810 Series Criticals

One of the most widely analyzed series of criticals is the Babcock & Wilcox (B&W) 1810 Series [13]. These critical experiments represent realistic core configurations and consist of a 5x5 array of either 15x15 PWR or 16x16 PWR assemblies. The central “assembly” was modified from one experiment to the next. Some cores contained gadolinium fuel pins, Ag-In-Cd (AIC), B4C control rods, or hollow rods. All core configurations from this set were analyzed, with the exception of Core 11, which was explicitly designed to measure resonance parameters.

The geometry of Cores 1 through 17 was representative of B&W and Westinghouse type reactors. These cores consisted of a 5x5 array of pseudo-assemblies (individual pins without spacers), each containing a 15x15 pin array. Cores 1 through 10 consisted of a uniform fuel enrichment distribution. Cores 12 through 17 consisted of a high enrichment central area surrounded by a low enriched zone (split zone enrichments).

The geometry of Cores 18 through 20 was representative of a Combustion Engineering type of reactor design. These cores consisted of a 5x5 array of pseudo-assemblies, each containing a 16x16 pin array. All of these cores contained a high enrichment central area surrounded by a low enriched zone. These cores differed only in the number of gadolinium fuel pins present.

Table I presents the critical eigenvalues for the B&W 1810 series of criticals from CASMO5 using the CASMO5 production ENDF/B-VII.0 library, and the new ENDF/B-VII.1beta4 and JENDL-4.0 libraries.

Table I. CASMO5 Results for the B&W 1810 Series

	Boron (ppm)	# 4% Gd Pins	#of AIC Rods	E7R0 k_{eff}	E7R1B4 k_{eff}	J4.0 k_{eff}
Core 01	1337.9	--	--	1.00124	1.00114	1.00101
Core 02	1250.0	--	16	1.00062	1.00052	1.00038
Core 03	1239.3	20	--	1.00082	1.00069	1.00069
Core 04	1171.7	20	16	1.00134	1.00123	1.00119
Core 05	1208.0	28	--	1.00049	1.00036	1.00038
Core 05a	1191.3	32	--	1.00038	1.00026	1.00030
Core 05b	1207.1	28	--	1.00057	1.00043	1.00045
Core 06	1155.8	28	16	1.00063	1.00049	1.00048
Core 06a	1135.6	32	16	1.00056	1.00043	1.00044
Core 07	1208.8	28	--	1.00052	1.00039	1.00041
Core 08	1170.7	36	--	1.00057	1.00044	1.00049
Core 09	1130.5	36	16	1.00039	1.00026	1.00028
Core 10	1177.1	36	16	1.00039	1.00025	1.00032
Core 12 (split)	1899.3	--	--	1.00145	1.00152	1.00088
Core 13 (split)	1635.4	--	16	1.00175	1.00179	1.00124
Core 14 (split)	1653.8	28	16	1.00110	1.00112	1.00068
Core 15 (split)	1479.7	28	16	1.00154	1.00155	1.00115
Core 16 (split)	1579.4	36	--	1.00106	1.00107	1.00068
Core 17 (split)	1432.1	36	16	1.00114	1.00112	1.00078
Core 18 (CE)	1776.8	--	--	1.00273	1.00280	1.00194

Core 19 (CE)	1628.3	16	--	1.00237	1.00243	1.00168
Core 20 (CE)	1499.0	32	--	1.00219	1.00221	1.00158
Average (Cores 01-17)				1.00087	1.00079	1.00064
Standard Dev.(Cores 01-17)				0.00044	0.00050	0.00032
Average (Cores 18-20)				1.00243	1.00248	1.00173
Standard Dev. (Cores 18-20)				0.00027	0.00030	0.00019
Average (All cores)				1.00108	1.00102	1.00079
Standard Dev. (All Cores)				**0.00069**	**0.00076**	**0.00049**

As can be seen in Table I, all three libraries perform quite well on this series of criticals over a wide range of burnable absorber types and loadings with a slight advantage going to the J4.0 evaluation. Of particular interest, is that the J4.0 results show some minor improvements for Cores 18-20 (the CE style cores with large water rods) which had previously been outliers.

6.2 DIMPLE Criticals S06A and S06B

This section presents results of the calculations for two core configurations from the AEA Winfrith DIMPLE criticals S06A and S06B. The fuel assembly is a PWR type with 16x16 uniform fuel rods at 3.0% U-235 enrichment. The core layout consists of five assemblies forming a cruciform core, both with and without a surrounding 2.67 cm thick stainless steel baffle. The significant amount of Fe in the stainless steel baffle is known to have a fairly large transport effect. The two cores taken together indicate how well CASMO5 is performing for the baffle/reflector calculation such as that found in a typical PWR. No excess reactivity was reported for these two cores. Table II shows the CASMO5 results for these cores and Fig. 2 shows the geometry of these two cores.

Table II. CASMO5 results for the DIMPLE criticals S06A and S06B

	E7R0 k_{eff}	**E7R1B4 k_{eff}**	**J4.0 k_{eff}**
S06A	1.00155	1.00153	1.00022
S06B	1.00131	1.00114	1.00016
Delta pcm	24	39	6

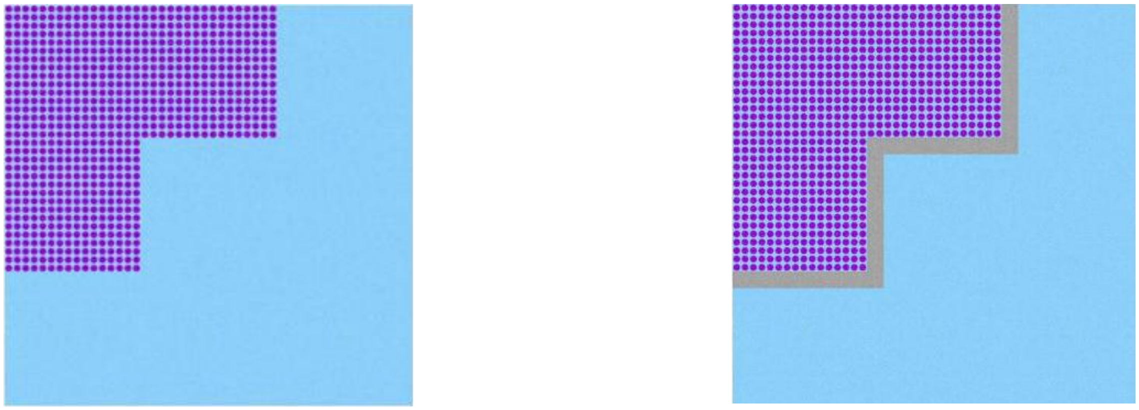

Figure 2. Dimple S06A no reflector and S06B with reflector.

With the coming use of heavy steel block reflectors in advanced PWR designs, results from the DIMPLE criticals help demonstrate that CASMO5 is performing well for these types of calculations. What is of interest in this particular set of results is the delta between reflector and no reflector cases. In this case the J4.0 evaluation again appears to perform slightly better than either the E7R0 or the E7R1B4 although all three libraries are actually performing very well.

6.3 TCA Iron Reflector Criticals

This section presents results of an experiment run in JAERI's Tank Critical Assembly (TCA) [14]. In this set of experiments, iron plates (ranging from a thickness of 0 cm to 15 cm thick) were added to two sides of a square lattice of 2.6 wt% enriched UO2 fuel pins and then criticality achieved by varying water level. There were two series of experiments run, one where the plates were flush to each other (as they were added) and a second series where water was allowed between the plates to simulate a 10% water mix by volume. Typical configurations for this experiment with 1 iron plate in place and 27 iron plates in place are shown in Fig. 3:

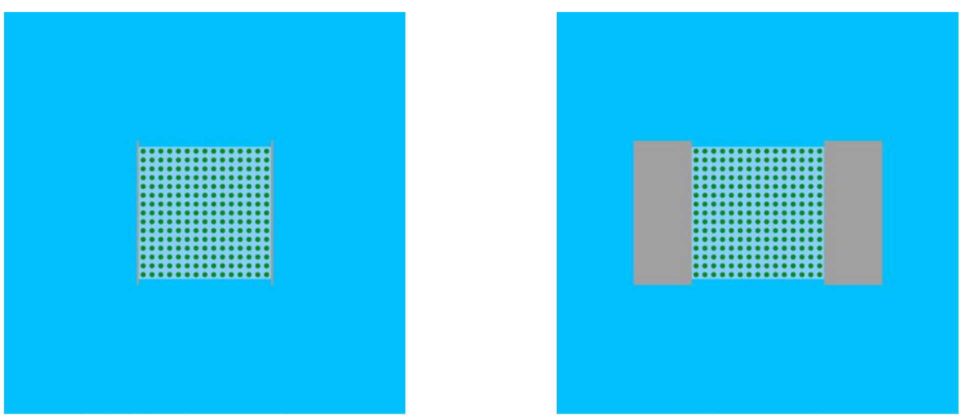

Figure 3. TCA reflector critical with 1 plate and 27 plates.

Table III. CASMO5 results for the TCA reflector criticals

# Plates	No Water Between Plates			10% Water Between Plates		
	E7R0 k_{eff}	E7R1B4 k_{eff}	J4.0 k_{eff}	E7R0 k_{eff}	E7R1B4 k_{eff}	J4.0 k_{eff}
0	0.99969	0.99964	0.99932	---	---	---
1	0.99905	0.99890	0.99869	---	---	---
5	0.99882	0.99868	0.99875	---	---	---
6	0.99902	0.99888	0.99897	0.99804	0.99789	0.99799
11	1.00005	0.99991	1.00005	0.99895	0.99881	0.99895
16	1.00055	1.00041	1.00056	0.99867	0.99852	0.99867
21	1.00100	1.00086	1.00102	0.99873	0.99859	0.99873
25	---	---	---	0.99782	0.99767	0.99781
27	1.00150	1.00136	1.00152	---	---	---
Average	0.99996	0.99983	0.99986	0.99844	0.99830	0.99843
Standard Deviation	**0.00099**	**0.00099**	**0.00109**	**0.00049**	**0.00049**	**0.00050**

These results again demonstrate that CASMO5 is performing very well with all three libraries even when very large quantities of iron are present. All three libraries yield almost identical results for this set of experiments.

6.4 PNL MOX 30-35 Criticals

Designated as MIX-COMP-THERM-002 in the International Handbook of Evaluated Criticality Safety Benchmark Experiments [15,16], this set of MOX critical experiments was performed in the Plutonium Recycle Critical Facility (PRCF) at Pacific Northwest Laboratory (PNL) in 1975-1976. The set of six MOX experiments uses natural UO2-2.0 wt% PuO2 (8% ^{240}Pu) fuel pins in square-pitched lattices in borated or pure water at room temperature. There are three lattice pitches: 0.70 inch (Cores 30-31), 0.87 inch (Cores 32-33), and 0.99 inch (Cores 34-35) and for each lattice type, there are two core configurations: one essentially unborated and one borated. These six MOX critical experiments are commonly referred to as PNL 30-35. Criticality in these cores is achieved by adjusting the boron concentration in water and the number of fuel rods. The MOX fuel used in these criticals was manufactured with a vibration compaction technique that leads to a fuel that essentially has a double heterogeneity similar to that found in TRISO fuel [17]. All these configurations are slightly supercritical. The CASMO5 results presented here are for a homogeneous composition of the fuel.

Table IV. CASMO5 Results for the PNL MOX criticals

	Boron (PPM)	Benchmark k_{eff}	MCNP5 E7R0 [16]	CASMO5 E7R1B4	CASMO5 J4.0
Core 30	1.7	1.0010+/-0.0059	1.0008+/-0.0003	1.0011	1.0011
Core 31	687.9	1.0009+/-0.0045	1.0031+/-0.0004	1.0014	1.0023
Core 32	0.9	1.0024+/-0.0029	1.0031+/-0.0003	1.0031	1.0038
Core 33	1090.4	1.0024+/-0.0021	1.0068+/-0.0003	1.0048	1.0065
Core 34	1.6	1.0038+/-0.0022	1.0045+/-0.0003	1.0039	1.0047
Core 35	767.2	1.0029+/-0.0024	1.0067+/-0.0003	1.0054	1.0068

$\sigma < |\Delta k| < 2\sigma$ $|\Delta k| > 2\sigma$

Adopting the color coded nomenclature of Ref. 16, the results look very similar to the E7R0 MCNP results for these MOX cases. The very soft spectrum in PNL-34/35 offers a unique opportunity to test the plutonium thermal cross section which is important not only in MOX cores but for normal UO2 depletion cases as well.

7. CONCLUSIONS

Two CASMO5, 586 group neutron data libraries were generated using state-of-the-art nuclear data (JENDL-4.0 and ENDF/B-VII.1beta4). At this point in time, the JENDL-4.0 CASMO5 library appears to perform slightly better overall than the ENDF/B-VII.1beta4 CASMO5 library, but the differences are very small. Both new libraries appear to be suitable for LWR analysis with CASMO5. Overall the E7R1B4 library appears to perform very similar to the E7R0 library. Of course there may well be improvements in applications of the data not examined here, i.e. fast reactors, thorium fuel cycles, etc.

A nuclear data evaluation is far removed from the actual dynamic environment found in an LWR fuel assembly in a commercial power reactor and has to address the needs of many nuclear communities (not just the LWR community). The committees that have worked on both evaluations should be commended for their efforts, as compiling this data is a huge undertaking. However, it is hoped that in the future the CSEWG committee will address the issue of delayed neutron data, fission yields, gadolinia thermal cross sections, and ^{239}Pu thermal cross sections.

Further testing and validation, including detailed depletion testing, of both evaluations is warranted to examine further differences. Pending depletion testing, the JENDL-4.0 CASMO5 neutron data library does appear to be of production quality. The final chapter for the ENDF/B-VII.1 evaluation and its application to LWR analysis with CASMO5 has yet to be written as the final version of the ENDF/B-VII.1 evaluation was released on December 22, 2011 and its processing into a production level library is well underway. From the experience gained here with the E7R1B4 library and its processing, few surprises are expected.

REFERENCES

1. J. Rhodes, D. Lee, K. Smith, "CASMO-5/CASMO-5M A Fuel Assembly Burnup Program Methodology Manual," SSP-08/405 Rev. 0 (2008).
2. K. Smith, J. Rhodes, "CASMO-4 Characteristics Methods for Two-dimensional PWR and BWR Core Calculations," *Trans. Am. Nucl. Soc*. **83**, 322, Washington D.C., Nov. (2000).
3. D. Lee, K. Smith and J. Rhodes, "The Impact of U-238 Resonance Elastic Scattering Approximation on Resonance on Thermal Reactor Doppler Reactivity," *Proceedings of the International Conference on the Physics of Reactors (PHYSOR-2008),* Interlaken, Switzerland, (2008).
4. A. Yamamoto, M. Tabuchi, N. Sugimura, T. Ushio and M. Mori, "Derivation of Optimum Polar Angle Quadrature Set for the Method of Characteristics Based on Approximation Error for the Bickley Function," *J. Nucl. Sci. Technol.*, **44**, Feb. (2007).
5. D. Lee, J. Rhodes, K.Smith, "Quadratic Depletion Model for Gadolinium Isotopes in CASMO-5," *Proceedings of Advances in Nuclear Fuel Management IV (ANFM 2009),* Hilton Head Island, SC, (2009).
6. J. Rhodes, K. Smith, Z. Xu, "CASMO-5 Energy Release per Fission Model," *Proceedings of the International Conference on the Physics of Reactors (PHYSOR-2008),* Interlaken, Switzerland, (2008).
7. K. Shibata, O. Iwamoto, T. Nakagawa, N. Iwamoto, A. Ichihara, S. Kunieda, S. Chiba, K. Furutaka, N. Otuka, T. Ohsawa, T. Murata, H. Matsunobu, A. Zukeran, So Kamada and J. Katakura, "JENDL-4.0: A New Library for Nuclear Science and Engineering," *J. Nucl. Sci. Technol.*, **48**, (2011).
8. G. Chiba, K. Okumura, K. Sugino, Y. Nagaya, K. Yokoyama, T. Kugo, M. Ishikawa and S. Okajima, "JENDL-4.0 Benchmarking for Fission Reactor Applications," *J. Nucl. Sci. Technol.*, **48**, (2011)
9. G. Leinweber, D. Barry, M. Trbovich, J. Burke, N. Drindak, H. Knox, and R. Ballad, R. Block, Y. Danon, L. Severnyak, "Resonance Parameter Measurements and Analysis of Gadolinium," (PHYSOR 2006), Vancouver, BC, Canada, (2006).
10. M. Hermann, "Development of ENDF/B-VII.1 and Its Covariance Component," *J. of the Korean Physical Society*, **59**, (2011).
11. P. Oblozinsky, and M. Herman, "Special Issue on Evaluated Nuclear Data File ENDF/B-VII.0," *Nuclear Data Sheets*, **107**, Number 12 (2006).
12. M. Hone, R. Pomirleanu, R. Knott, G. Wikmark, "Gray Rod Cluster Assembly Design for the Westinghouse AP1000® Reactor," *Proceedings of the 2011 Water Reactor Fuel Performance Meeting*, Chengdu, China, (2011).

13. L.W. Lewman, “Urania-Gadolinia: Nuclear Model Development and Critical Experiment Benchmark,” B&W 1810, DOE/ET/34212-41, Babcock & Wilcox (1984).
14. Y. Tahara, H. Sekimoto, Y. Miyoshi, “Reactivity Effect of Iron Reflector in LWR Core,” *J. Nucl. Sci. Technol.*, **38**, (2001).
15. H-K. Joo, “Rectangular Arrays of Water-Moderated UO2-2 wt% PuO2 (8% 240Pu) Fuel Rods,” MIXCOMP-THERM-002, International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC/(95)03/VI (2008).
16. R. Mosteller, “ENDF/B-VII.0, ENDF/B-VI, JEFF3.1 and JENDL 3.3 Results for Critical Lattices of Fuel Pins in Water,” *Proceedings of Conference on Advances in Nuclear Fuel Management IV, (ANFM 2009)*, Hilton Head, NC (2009).
17. Z. Xu, K. Smith and J.Rhodes,”Benchmarking CASMO-5 Against PNL Mixed Oxide Criticals,” *Proceedings of Advances in Reactor Physics to Power the Nuclear Renaissance, (ICAPP 2010)*, Pittsburgh, PA, (2010).