ATTACHMENT 3 TO NL-15-089

NETCO DOCUMENT – "INTRPND3: VERIFICATION AND VALIDATION REPORT MARCH 2014"

(NON-PROPRIETARY)

ENTERGY NUCLEAR OPERATIONS, INC.
INDIAN POINT NUCLEAR GENERATING UNIT NO. 2
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INTRPND3:

Verification and Validation

Verification and Validation Report, March 2014

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This report describes worked performed by NETCO and its Subcontractors.

The report is a corporate document that should be cited in the literature in the following manner:

INTRPND3: Verification and Validation, NETCO, Lake Katrine, NY: 2014.

SOFTWARE DESCRIPTION

INTRPND3 is a Fortran[1] program containing algorithms for performing automated burnup interpolation and decay time correction of nuclide isotopics for spent nuclear fuel from output files generated by the SCALE 6[2] TRITON depletion sequence.

Description

The following report documents the verification and validation of INTRPND3, which incorporates additional options for interpolating among multiple axial power shapes.

Benefits and Value

INTRPND3 provides the user with an automated means for interpolating the spent fuel isotopic concentrations for specific burnups and cooling times, rather than having to execute the SCALE 6.1 t5-depl depletion sequence via TRITON for each desired depletion state. Some of the advantages of an automated interpolation routine system for dry cask storage operations are:

- Ability to decay correct nuclide concentrations for cooling time.
- Ability to interpolate nuclide concentrations between assembly average burnups.
- Ability to interpolate nuclide concentrations between axial power shapes.

INTRPND3 can accomplish the above tasks without the time intensive requirement to execute TRITON each time to obtain these isotopic characteristics.

Platform Configuration

The Verification and Validation of INTRPND3 was performed on an Intel Pentium PC running under the 64-bit Windows 7 operating system.

ABSTRACT

The INTRPND3 Fortran software program facilitates the interpolation of node specific isotopics between assembly average burnup values and scales them for a depletion dependent axial power profile. A decay correction is performed to correct the nuclide number densities for a desired cooling time of interest. This report describes the independent methods used to verify and validate the interpolation and decay algorithms for selected isotopic concentrations output by INTRPND3.

A reference case was selected for execution with SCALE 6.1.2 such that isotopic concentrations generated via an independent SCALE 6.1.2 calculation were available for comparison with interpolated isotopics generated with INTRPND3. Comparisons via EXCEL spreadsheets confirmed the INTRPND3 calculations. Evaluation of these comparisons provides the bases for concluding that, when used as intended, INTRPND3 software constitutes a reliable methodology to generate nuclide isotopic concentrations for input into the KENO V.a Monte-Carlo criticality code.

CONTENTS

(NOTE: The non-proprietary version of this report does not contain Appendix A)

List of Tables

1
INTRODUCTION

INTRPND3, developed by CTR Technical Services, is a user-friendly Fortran-based interpolation algorithm. The program is approximately 1100 lines long and is capable of reading a list directed input file to read in a library of standard depletion dependent isotopics, calculation parameters and axial power shapes. For the purpose of generating burnup and cooling time specific isotopics, INTRPND3 accepts user-supplied depletion parameters. These parameters may include burnup, cooling time, BPR burnup, axial power shape, spent fuel pool temperature and initial fuel enrichment. INTRPND3 algorithms allow the user to select from different axial power shape formats for interpolation (scaling) nodal burnup shapes as a function of assembly average burnup.

INTRPND3 supports the following basic operational tasks:

- Defining Axial Power Shape Files,
- Selecting SCALE 6.1(TRITON) generated OPUS PLT files containing depletion isotopics
- Specifying burnup interpolation point,
- Specifying cooling time decay point,
- Specifying nuclides of interest and excluding others from the interpolation,
- Generating KENO V.a formatted isotopic input.

Decay constants and daughter products are hard coded into the INTRPND3 algorithms.

2 VERIFICATION AND VALIDATION METHOD

The verification of INTRPND3 consisted of the inspection and code tracing of the 1100+ lines of code contained in Appendix A. The method employed to validate INTRPND3 followed these basic steps to define a depletion case for an Indian Point Unit 2 fuel assembly following EPRI depletion benchmark case 3:

- Create a TRITON depletion case for EPRI Depletion Benchmark, Case 3 at 60 GWD/MTU and 100 hours cooling.
- Deplete with the t5-depl sequence in TRITON.
- Extract depletion dependent isotopics with OPUS.
- Define INTRPND3 input file "INTRPND.in".
- Define Axial Power Shape File.
- Execute INTRPND3

3 INTRPND3 INPUT FILE

The input parameters defined for the verification and validation case were based on EPRI Depletion Case 3 from Reference X. Table 3-1 below lists the parameters for each line of input defined in "INTRPND.in" used in the validation of INTRPND3 which is contained in Appendix B.

Table 3-1
Design Basis Fuel Assembly Parameters

Line	Parameter	Value
1	Axial Shape File	shapes1.txt
2	Output File Name	INTRPND3VALIDATION.kno
3	Number of PLT Files to read from, n	1
4	PLT File Names(n of these)	case3ipepri2.00000000000000000.plt
5	Lower Burnup Boundaries for PLT files(n of these)	0
6	Assembly enrichment(w/o)	4.25
7	Power Density(W/gm)	38.1
8	Temperature of Keno Input(K)	293.00
9	Cooling Time to Decay (Time, Units)	100 hour
10	Assembly Average Burnup (max)(MWD/MTU)	60000
11	Unit No. for Keno Material	10
12	Shape Interpolation Flag	0
13	Nuclides to omit	Xe-135

14	Nuclides to omit	Np-239

All of the parameters above were defined directly in the ASCII INTRPND3 input file. File lengths may vary if the number of PLT files varies and/or the number of nuclides to omit varies.

4 RESULTS AND DISCUSSION

The INTRPND3 and TRITON results of the nuclide interpolation and cooling time correction for the nuclide concentrations are listed below in Table 4-1. Column one contains the isotope, while columns 2 and 3 contain the decay-time-corrected nuclide concentrations from INTRPND3 and TRITON respectively. Column 4 contains the percent difference between the two methods (i.e., [(INTRPND3-OPUS)/INTRPND3 x 100%]). Highlighted percent differences shown in the table exceeded ±1%.

Table 4-1
INTRPND3 and SCALE 6.1.2 Nuclide Concentrations for EPRI Depletion Case 3 at 60GWD/MTU and 100hr Cooling Time.

Nuclide	INTRPND3	OPUS	%
te-129m	5.8435E-08	5.880E-08	-0.625%
eu-152	4.9441E-10	4.944E-10	0.002%
eu-151	6.8003E-10	6.800E-10	0.004%
se-76	9.4460E-10	9.467E-10	-0.222%
pm-151	9.7315E-10	9.808E-10	-0.786%
gd-152	1.4510E-09	1.452E-09	-0.069%
cd-115m	1.5175E-09	1.518E-09	-0.034%
la-138	1.5550E-09	1.555E-09	0.000%
ge-73	2.7910E-09	2.792E-09	-0.036%
er-166	2.9750E-09	2.987E-09	-0.403%
rb-86	2.9542E-09	2.953E-09	0.040%
ru-99	3.2287E-09	3.233E-09	-0.132%
sb-124	4.1195E-09	4.120E-09	-0.011%
xe-129	3.9450E-09	3.949E-09	-0.101%
dy-164	4.6790E-09	4.679E-09	0.000%
sn-125	3.5340E-09	3.535E-09	-0.028%
tb-160	5.7766E-09	5.777E-09	-0.007%
gd-155	5.8245E-09	5.826E-09	-0.025%
cd-113	7.7870E-09	7.956E-09	-2.170%
gd-157	7.3240E-09	8.287E-09	-13.149%
ho-165	8.7500E-09	8.754E-09	-0.046%
ce-143	1.0315E-08	1.033E-08	-0.149%
te-127m	3.7337E-08	3.890E-08	-4.185%
sm-153	1.1749E-08	1.183E-08	-0.687%
rh-105	1.2928E-08	1.308E-08	-1.176%
y-90	1.3245E-08	1.373E-08	-3.658%
pm-149	1.4788E-08	1.514E-08	-2.379%

as-75	1.6210E-08	1.621E-08	0.000%
dy-163	1.6540E-08	1.654E-08	0.000%
np-238	1.6714E-08	1.671E-08	0.027%
ag-111	1.8872E-08	1.890E-08	-0.148%
dy-162	2.0640E-08	2.064E-08	0.000%
dy-160	2.0795E-08	2.079E-08	0.026%
sn-115	2.2240E-08	2.229E-08	-0.225%
cm-243	2.5713E-08	2.571E-08	0.012%
am-242m	2.6199E-08	2.619E-08	0.033%
dy-161	2.7210E-08	2.743E-08	-0.809%
te-124	3.2542E-08	3.254E-08	0.008%
sn-123	1.0424E-08	1.042E-08	0.042%
pm-148	3.1578E-08	3.172E-08	-0.450%
cs-136	3.7996E-08	3.799E-08	0.015%
te-122	4.1460E-08	4.162E-08	-0.386%
ge-76	4.2840E-08	4.284E-08	0.000%
te-126	5.3520E-08	5.361E-08	-0.168%
cm-246	5.9890E-08	5.989E-08	0.000%
pm-148m	6.5263E-08	6.526E-08	0.004%
ba-135	7.1970E-08	7.199E-08	-0.028%
mo-99	7.6199E-08	7.624E-08	-0.053%
te-132	8.1766E-08	8.053E-08	1.511%
gd-160	8.0460E-08	8.046E-08	0.000%
se-77	9.6550E-08	9.668E-08	-0.135%
sr-86	9.5305E-08	9.530E-08	0.005%
ag-110m	1.0271E-07	1.027E-07	0.006%
kr-82	1.0570E-07	1.061E-07	-0.378%
la-140	1.0247E-07	1.084E-07	-5.792%
in-115	1.1830E-07	1.193E-07	-0.844%
sm-149	1.3934E-07	1.402E-07	-0.616%
tb-159	1.8430E-07	1.846E-07	-0.163%
sn-116	2.0940E-07	2.094E-07	0.000%
u-237	2.1180E-07	2.118E-07	0.001%
nd-147	2.3092E-07	2.311E-07	-0.077%
gd-154	2.3817E-07	2.381E-07	0.031%
i-131	2.4794E-07	2.574E-07	-3.817%
eu-156	2.5487E-07	2.553E-07	-0.170%
xe-133	2.5347E-07	3.063E-07	-20.843%
te-125	3.5535E-07	3.554E-07	-0.013%
sb-121	3.6980E-07	3.703E-07	-0.135%
sn-119	3.9860E-07	3.987E-07	-0.025%
sn-120	4.0570E-07	4.057E-07	0.000%
xe-128	3.8120E-07	3.812E-07	0.000%
cm-245	4.0670E-07	4.067E-07	0.000%
sn-118	4.1650E-07	4.165E-07	0.000%
sn-117	4.4820E-07	4.484E-07	-0.045%
sb-123	4.7214E-07	4.721E-07	0.008%
cd-116	4.9960E-07	4.996E-07	0.000%
sn-122	5.0820E-07	5.082E-07	0.000%
eu-155	5.7774E-07	5.778E-07	-0.010%

sm-151	6.2675E-07	6.268E-07	-0.008%
sb-125	6.4608E-07	6.461E-07	-0.003%
ba-140	7.2898E-07	7.290E-07	-0.003%
pr-143	7.2804E-07	7.291E-07	-0.145%
xe-130	7.3050E-07	7.312E-07	-0.096%
cm-242	7.5518E-07	7.591E-07	-0.518%
sn-124	7.8730E-07	7.873E-07	0.000%
cd-112	1.2710E-06	1.273E-06	-0.157%
cd-114	1.4330E-06	1.433E-06	0.000%
sr-89	1.4478E-06	1.448E-06	-0.012%
se-80	1.5470E-06	1.547E-06	0.000%
gd-158	1.6140E-06	1.614E-06	0.000%
sn-126	1.7010E-06	1.701E-06	0.000%
am-241	1.7282E-06	1.728E-06	0.009%
eu-154	1.9262E-06	1.927E-06	-0.040%
ce-141	1.9974E-06	2.009E-06	-0.582%
ba-136	2.0663E-06	2.067E-06	-0.033%
nd-142	2.1750E-06	2.178E-06	-0.138%
nb-95	2.2636E-06	2.264E-06	-0.018%
y-91	2.2930E-06	2.309E-06	-0.700%
br-81	2.4410E-06	2.441E-06	0.000%
cd-111	2.5429E-06	2.543E-06	-0.004%
sm-154	2.6440E-06	2.644E-06	0.000%
ru-103	2.8477E-06	2.848E-06	-0.011%
kr-85	2.6121E-06	2.613E-06	-0.035%
u-234	3.2759E-06	3.276E-06	-0.002%
i-127	3.5390E-06	3.549E-06	-0.283%
se-82	3.8590E-06	3.859E-06	0.000%
zr-95	3.9545E-06	3.955E-06	-0.012%
kr-83	4.0270E-06	4.028E-06	-0.025%
ba-137	4.3955E-06	4.395E-06	0.012%
cm-244	4.4790E-06	4.479E-06	0.001%
sm-147	4.5378E-06	4.538E-06	-0.005%
pd-110	5.2210E-06	5.221E-06	0.000%
sm-152	5.3620E-06	5.362E-06	0.000%
cd-110	5.4802E-06	5.480E-06	0.004%
mo-96	6.6650E-06	6.665E-06	0.000%
ba-134	6.8359E-06	6.836E-06	-0.002%
te-128	7.4750E-06	7.476E-06	-0.013%
eu-153	7.5168E-06	7.516E-06	0.010%
ag-109	7.5170E-06	7.530E-06	-0.173%
pm-147	8.2317E-06	8.232E-06	-0.003%
am-243	8.2250E-06	8.233E-06	-0.097%
gd-156	8.5303E-06	8.530E-06	0.004%
pu-238	1.0551E-05	1.055E-05	0.012%
rb-85	1.0632E-05	1.063E-05	0.018%
sm-148	1.1737E-05	1.174E-05	-0.024%
nd-150	1.2050E-05	1.205E-05	0.000%
i-129	1.1950E-05	1.195E-05	0.000%
cs-134	1.2482E-05	1.248E-05	0.017%

kr-84	1.2690E-05	1.269E-05	0.000%
ru-106	1.3723E-05	1.372E-05	0.023%
ce-144	1.5739E-05	1.574E-05	-0.003%
pd-108	1.5760E-05	1.576E-05	0.000%
ru-100	1.6260E-05	1.626E-05	0.000%
kr-86	2.0050E-05	2.005E-05	0.000%
sm-150	1.9260E-05	1.926E-05	0.000%
np-237	1.9623E-05	1.962E-05	0.016%
pd-107	2.3380E-05	2.338E-05	0.000%
nd-148	2.4630E-05	2.463E-05	0.000%
rb-87	2.6020E-05	2.603E-05	-0.038%
xe-131	2.6327E-05	2.633E-05	-0.010%
pu-242	2.6720E-05	2.672E-05	0.000%
pd-106	2.7587E-05	2.759E-05	-0.012%
te-130	2.9220E-05	2.922E-05	0.000%
cs-135	2.9661E-05	2.966E-05	0.004%
pd-104	3.1050E-05	3.105E-05	0.000%
sr-88	3.4870E-05	3.488E-05	-0.029%
rh-103	3.6897E-05	3.689E-05	0.020%
pd-105	4.0288E-05	4.029E-05	-0.005%
nd-145	4.0900E-05	4.091E-05	-0.024%
y-89	4.4875E-05	4.488E-05	-0.011%
nd-143	4.5308E-05	4.531E-05	-0.005%
pu-241	4.7674E-05	4.767E-05	0.008%
nd-146	5.0320E-05	5.032E-05	0.000%
sr-90	5.3356E-05	5.336E-05	-0.008%
zr-91	5.7306E-05	5.731E-05	-0.007%
ru-104	5.7510E-05	5.751E-05	0.000%
mo-95	6.7128E-05	6.712E-05	0.012%
zr-93	7.1410E-05	7.144E-05	-0.042%
tc-99	7.3842E-05	7.385E-05	-0.011%
pr-141	7.4196E-05	7.419E-05	0.008%
ru-101	7.4280E-05	7.428E-05	0.000%
cs-133	7.5646E-05	7.567E-05	-0.031%
pu-240	7.6112E-05	7.611E-05	0.002%
ce-142	7.6790E-05	7.679E-05	0.000%
nd-144	7.9331E-05	7.933E-05	0.001%
zr-96	8.0510E-05	8.051E-05	0.000%
mo-97	8.0160E-05	8.021E-05	-0.062%
ru-102	8.1900E-05	8.190E-05	0.000%
mo-98	8.3150E-05	8.315E-05	0.000%
ce-140	8.4369E-05	8.437E-05	-0.001%
la-139	8.5030E-05	8.504E-05	-0.012%
cs-137	8.6087E-05	8.609E-05	-0.003%
xe-132	8.8887E-05	8.889E-05	-0.004%
ba-138	9.2170E-05	9.218E-05	-0.011%
mo-100	9.2290E-05	9.229E-05	0.000%
xe-134	1.1140E-04	1.114E-04	0.000%
u-235	1.2690E-04	1.269E-04	0.000%
u-236	1.3880E-04	1.388E-04	0.000%
pu-239	1.5542E-04	1.547E-04	0.466%
xe-136	1.6740E-04	1.674E-04	0.000%
u-238	2.1020E-02	2.102E-02	0.000%
o-16	4.6140E-02	4.614E-02	0.000%

For the nuclide concentration calculations performed, INTRPND3 and SCALE 6.1.2 were in general agreement to less than 1% for all but 10 of the 185 selected Actinides and Fission Products. Differences for the primary percentage differences for Actinides were typically close to 0% except for Pu-239 for which the INTRPND3 interpolated value was high by 0.5%.

For the 10 number densities that were different by more than 1%, nine of the concentrations were conservatively low when interpolated by INTRPND3. The single exception was Te-132 which was high by approximately 1.5%. Accordingly and importantly, the Keno V.a k_{eff} calculations using the number densities from both INTRPND3.exe and from the direct TRITON calculated isotopic number densities differed by less than $0.0004\Delta k$ (except at 25 years cooling with INTRPND3 was conservative by $0.0007\Delta k$). Thus, computed differences in isotopic number densities are not observed to have meaningful influence on corresponding calculated k values. Furthermore, this allowed validation of the fact that INTRPND3 output files can be read by KENO V.a and used to successfully complete a k_{eff} calculation.

5 CONCLUSIONS

Based on the calculations above, INTRPND3a is performing its designed function in calculating interpolated number densities for intermediate burnup points and cooling times. In addition, the program is calculating nodal isotopics for selected axial power profiles consistent with the methodology.

6 REFERENCES.

1. Leestma, S. and L. Nyhoff, Fortran 90 For Engineers and Scientists, 2nd Edtion, MacMillian Publishing Co., New York, 1988.

2. *Scale: A comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1, June 2011. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-785.

A INTRPND3.FOR PROGRAM LISTING

[Source code removed for Non-Proprietary Version]

B INPUT FILE LISTING

shapes1.txt

INTRPND3VALIDATION.kno

1

case3ipepri2.00000000000000000.plt

0

4.25

38.1

293.00

100 hour

60000

10

0

xe-135

np-239

C USER GUIDE

RUNNING INTRPND3:

INTRPND3 can be executed from the DOS command line via the command:

> "C:\path\intrpnd3 INTRPND.in" where path is the directory or folder containing the executable file.

INTRPND.in has the format shown in Appendix B. Several files must be located in the current directory, namely:

- The Axial Power Shape file, (e.g., "Shapes.txt")
- Opus *.PLT files

PLT files

The number of PLT files will vary for each case. For example, if the assembly depletion involves using BPRs, then a single PLT file will be generated for depletion to the point of BPR removal and a separate PLT file will be generated for depletion through end of cycle. Line 4 of the input file will contain the burnup at which BPR removal occurs (or 0 if no BPRs are used).

Axial Power Shapes

A single ASCII file containing axial relative power shapes must be present in the same directory as the executable. The file can contain a single power shape, or a series of power shapes as a function of burnup. The format should be as shown below:

```
SIF

BURNUP1  NODES  RPO -RPNODES

.

.

BURNUPn  NODES  RPO -RPNODES
```

(NOTE: Comments are indicated with a $ card)

SIF is the Shape Information Flag for interpolating (0= histogram, 1= interpolate between profiles in a conservative manner, 2 = interpolate between burnup step mid-points). For options 1 and 2, the number of axial nodes must be the same for each profile.

The sample format below assumes all profiles are at a flat (average) power distribution (single axial node).

```
0    $ shape interpolation flag (0=histogram, 1=interpolate betw profiles
     $ in a conservative manner, 2=interpolate betw mid points)
     $ for 1 and 2, the number of nodes must be the same for each profile
6000  $ burnup end point of first profile (MWD/MTU)
$ for each profile, the first integer is the number of nodes in the profile
1 1.0
10000  $ burnup end point of 2nd profile (MWD/MTU)
1 1.0
14000  $ end point of 3rd profile
1 1.0
```

Omitting Nuclides

Nuclides may be omitted by entering their alphanumeric ID as shown in Appendix B.

IF the nuclide is Promethium-149 (pm-149), then an additional entry must be entered following the nuclide ID's. The entry is a decimal multiplier by which the Pm-149 concentration will be adjusted