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Software Verification of VARPOW

Nuclear Science and Engineering Division

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prepared by

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REVISION HISTORY

Revision No.	Date	Section(s) Affected	Description
0	June 2024	All	First Version of Report
1	Dec. 2024	Sections 1, 4	Provide a link between the capabilities identified to be verified to the verification work presented in this report.

ABSTRACT

The VARPOW program is a post-processing utility program for DIF3D, specifically DIF3D-VARIANT, and it was developed to provide interface files for the thermal analysis program DASSH. The basic methodology of VARPOW is to take the neutron and gamma flux (moments) calculated by DIF3D (or GAMSOR) and combine them with the heating (coefficient) cross sections to calculate the spatial power distributions using the DIF3D-VARIANT spatial basis. VARPOW can use the output from GAMSOR (both steady state neutron and gamma flux calculations) or standard DIF3D/REBUS calculations (neutron flux only). The correct approach for defining the power distribution is to use GAMSOR as its purpose was to properly compute the gamma heating throughout the modeled domain. The power desnities calculated by VARPOW are broken into fuel, cladding and coolant terms for which isotope-wise categorization is needed. VARPOW has built in options the user can select for the isotope categorization or VARPOW can import a file that details the isotope categorization. VARPOW can export the solution in the polynomial basis of DIF3D-VARIANT or the monomial basis of DIF3D-VARIANT. The purpose of this work is to verify the power distribution results calculated by VARPOW from both the GAMSOR and DIF3D input options and verify that the input and output options are consistent with the manual. Hand calculation and independent numerical calculation are used for this verification work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Introduction

The VARPOW program [1] is a post-processing utility program for DIF3D [2], specifically DIF3D-VARIANT [3,4]. As covered in [1], the VARPOW program was built to provide power distribution details for a follow-on steady state thermal-hydraulic analysis. Its primary purpose is to act as the interface between DASSH [5] and DIF3D-VARIANT. DASSH is an alternative thermal analysis capability to the SE2ANL software which is based upon Superenergy-2 [6]. Some context is thus required as to the needs of DASSH and SE2ANL to understand VARPOW and its output.

Both DASSH and SE2ANL provide a steady state temperature distribution in a fast reactor with ducted fuel assemblies. The VARPOW approach is not constrained to this geometric detail but is only intended to take a given DIF3D solution and compute a three component (fuel, cladding, and coolant) decomposition of the power distribution. VARPOW does not do the spatial dehomogenization of the power distribution as that is handled in DASSH. The Superenergy-2 software was designed to take a user power distribution as input along with basic assembly geometry details and assembly flow specifications. The SE2ANL software is effectively a wrapper around Superenergy-2 which handles the interface with DIF3D (as part of GAMSOR [7]) to obtain the pin power details that Superenergy-2 needs as input. There is no such wrapper with DASSH. Instead, DASSH imports the spatial power distribution details from VARPOW and does the necessary spatial dehomogenization to construct pin, clad, coolant, and duct power distributions.

VARPOW does not require an input file and only has command line arguments and an optional input file to define the isotope categorization for fuel, structure, and coolant components. When VARPOW is executed without a valid number of arguments, it errors out and provides the input syntax format description seen in Figure 1-1. When it runs correctly, it will produce the Output.VARPOW, VariantMonoExponents.out, and MaterialPower.out files described in Figure 1-1 on lines 28 to 30. From the description in Figure 1-1, one can see that there are two execution options of VARPOW depending upon whether the input source is GAMSOR or standard DIF3D/REBUS:

1) For GAMSOR: varpow.x <iTypeFuel> <iTypeCool> <iOutput> <PMATRX> <LABELS> <GEODST> <NDXSRF> <ZNATDN> <NHFLUX> <GHFLUX>
2) For DIF3D: varpow.x <iTypeFuel> <iTypeCool> <iOutput> <ISOTXS> <LABELS> <GEODST> <NDXSRF> <ZNATDN> <NHFLUX>

The definitions of these files are also provided in Figure 1-1. The main difference between the two execution options is the inclusion of the PMATRX file (GAMSOR route) or ISOTXS file (DIF3D/REBUS route). To avoid confusion as DIF3D is involved in both pathways, we will refer to the input to VARPOW as using PMATRX or ISOTXS from this point on. For the PMATRX input path, the gamma NHFLUX file produced by GAMSOR, referred to as GHFLUX, is also

needed. With the ISOTXS input path, the GHFLUX is not available and thus the number of arguments is not the same between these input options. The PMATRX file stores the neutron and gamma heating cross section data and the GHFLUX file stores the gamma flux moments, while the ISOTXS file stores just the neutron cross section data and a energy conversion factor. The reader is referred to reference [7] for further details on the cross section data setup and differences between these approaches.

```
01 [VARPOW]..........................................................................
02 [VARPOW]...VARPOW utility program 11.3277  07/29/22
03 [VARPOW]...GAMSOR: varpow.x <iTypeFuel> <iTypeCool> <iOutput> <PMATRX> <LABELS> <GEODST> <NDXSRF> <ZNATDN> <NHFLUX> <GHFLUX>
04 [VARPOW]...DIF3D:  varpow.x <iTypeFuel> <iTypeCool> <iOutput> <ISOTXS> <LABELS> <GEODST> <NDXSRF> <ZNATDN> <NHFLUX>
05 [VARPOW]...  iTypeFuel:  The type of fuel form: 1,2,3,4   = Zr-alloyed,Oxide,Nitride,Alum Alloyed
06 [VARPOW]...  iTypeCool:  The type of coolant:   1,2,3,4,5 = Na, NaCl, Pb, Pb-Bi, Sn
07 [VARPOW]...  iOutput  :  M -> Monomial   :: normalized neutron heating(1), normalized gamma heating(2), fast flux (3)
08 [VARPOW]...           :  P -> Polynomial ::            neutron heating(1),           gamma heating(2), fast flux (3)
09 [VARPOW]...           :  S -> Monomial   :: norm fuel(1),clad(2),cool(3) neutron heat,norm fuel(4),clad(5),cool(6) gamma heat, fast flux (7)
10 [VARPOW]...           :  T -> Polynomial ::      fuel(1),clad(2),cool(3) neutron heat,     fuel(4),clad(5),cool(6) gamma heat, fast flux (7)
11 [VARPOW]...  PMATRX   :  The file name for the PMATRX cross section file
12 [VARPOW]...  ISOTXS   :  The file name for the ISOTXS cross section file
13 [VARPOW]...  LABELS   :  The file name for the LABELS file
14 [VARPOW]...  GEODST   :  The file name for the GEODST file
15 [VARPOW]...  NDXSRF   :  The file name for the NDXSRF file
16 [VARPOW]...  ZNATDN   :  The file name for the ZNATDN file
17 [VARPOW]...  NHFLUX   :  The file name for the DIF3D-VARIANT neutron NHFLUX file
18 [VARPOW]...  GHFLUX   :  The file name for the DIF3D-VARIANT gamma   NHFLUX file
19 [VARPOW]..........................................................................
20 [VARPOW]...AssignIsotope.inp is an optional input file to over-ride the default fuel,clad,cool assignments of isotopes:
21 [VARPOW]...  It should be placed in the current working directory and is a free format input with three keyword inputs
22 [VARPOW]...    COOLANT  NAR  CLR              ! COOLANT <MCC name or ISOTXS name> ...
23 [VARPOW]...    FUEL     U235_7 U238_7 PU239_7   ! FUEL    <MCC name or ISOTXS name> ...
24 [VARPOW]...    FUEL     816X01 O16R22 O16__7
25 [VARPOW]...    CLAD     FE56_7 NI60_7 MO94Q     ! CLAD    <MCC name or ISOTXS name> ...
26 [VARPOW]..........................................................................
27 [VARPOW]...Output consists of three data files:
28 [VARPOW]...  Output.VARPOW           :  The NHFLUX formatted file containing power density (w/cc in 3 or 6 pieces) and fast flux distribution
29 [VARPOW]...  VariantMonoExponents.out :  The monomial exponents of the Ritz spatial approximation in the neutron/gamma data set
30 [VARPOW]...  MaterialPower.out        :  The power density (w/cc) in each mesh fuel(1),clad(2),cool(3) neutron & fuel(4),clad(5),cool(6) gamma
31 [VARPOW]..........................................................................
32 [VARPOW]...Incorrect number of command arguments
```

Figure 1-1. VARPOW Invalid Input Execution Excerpt

The preferred approach for defining the power for DASSH and SE2ANL is to use GAMSOR as it properly distributes the gamma heating throughout the modeled domain. However, for preliminary reactor analysis work, the regular DIF3D/REBUS power methodology can be used as line 4 Figure 1-1 of indicates. Combined, these two execution paths require the PMATRX, ISOTXS, LABELS, GEODST, NDXSRF, ZNATDN, NHFLUX, and GHFLUX files which are all interface files generated by the Argonne codes DIF3D, MC^2-3, REBUS, and GAMSOR. LABELS, GEODST, NDXSRF, ZNATDN are the four basic components to define the geometry and compositions of the problem being solved and the other files have already been discussed. A detailed description and purpose of each interface file can be found in the VARPOW user manual [1] and thus further discussion of them here is not necessary.

Besides the required interface files, VARPOW needs three command line inputs: 1) iTypeFuel, 2) iTypeCool, and 3) iOutput. The first two are used to select the built in classification of isotopes into fuel, clad and coolant components. The iOutput option is used to select how the power distribution is exported. All of the input options used to execute VARPOW are tested and their impact upon the output is verified consistent with reference [8].

The command line input iTypeFuel refers to the fuel form, which from the description in Figure 1-1, there are four options: a) Zr-alloyed metal fuel, b) oxide (e.g., UO2 or PuO2), c) nitride (e.g., UN or PuN), and d) aluminum-alloyed (e.g., U-Al). Note that the list of options is not exhaustive for all possible fast reactor fuel forms (carbide as an example). It should be mentioned that the fission product isotopes in depleted fuel are common components of structural materials. The stated VARPOW methodology assumes that these isotopes will be part of the structural (or clad) materials. The basic reasoning is that the dominant portion of the power derived from these isotopes will appear in the structural material as opposed to the fuel because of the substantially higher density. It is important to note that structural material and clad material are used interchangably when it comes to the VARPOW output in this report. This is primarily as both the fuel and coolant components are assumed to be separate geometric components as is the "structural" component but the latter geometric separation (cladding, wire-wrap, duct, etc…) are unknown and assumed to be further seperable by the end user of the VARPOW output.

The command line input iTypeCool refers to the system coolant which the description in Figure 1-1 indicates there are five options: a) sodium (Na), b) molten salt (NaCl), c) lead (Pb), d) lead-bismuth eutectic (Pb-Bi), and e) molten tin (Sn). Again, the list of available coolants is not exhaustive but should serve the needs of most designs. After some test calculations it was determined that not all of these options are presently working.

The command line input iOutput controls the structure of the binary output file Output.VARPOW (this is a NHFLUX formatted file). Figure 1-1 shows there are four possible options: M, P, S, and T. The M and S options cause VARPOW to produce the output in a monomial basis while the P and T options will generate output with a polynomial basis. Which basis is used is simply a developer preference with respect to DASSH or some alternative follow-on analysis capability. The file VariantMonoExponents.out is needed for either option as it provides the monomial basis details and the matrix that allows one to translate between the polynomial and monomial basis.

As seen in Figure 1-1, option M will provide a neutron and gamma power distribution while S will provide a three component (fuel, structure, coolant) neutron and gamma power distribution. Similarly, option P will provide a neutron and gamma power distribution while option T will provide a three component neutron and gamma power distribution. The fast flux spatial distribution is also provided in all options. Options M and S indicate the monomial spatial distributions are normalized. Another file produced by VARPOW is MaterialPower.out. It is typical process of the design work that the thermal analysis code, DASSH or SE2ANL, will renormalize the power. With a monomial basis, the normalization is not a trivial process and thus they are prenormalized to 1.0 such that the follow-on code can simply multiply the power information in MaterialPower.out with the spatial distribution in Output.VARPOW and only focus on normalizing the power information in MaterialPower.out. For the polynomial basis, the

normalization is a simple scaling constant applied to all values in Output.VARPOW and thus MaterialPower.out is not really needed.

In addition to these required command line input arguments, VARPOW has an optional input file called AssignIsotope.inp which allows the user to directly assign isotopes to a particular material classification (fuel, structure, or coolant). When processing region-homogenized isotopic results from DIF3D or REBUS, AssignIsotope.inp allows the individual results to be regrouped accordingly to their respective classification. If not explicitly assigned in AssignIsotope.inp, VARPOW will use the algorithm outlined in Table 1.1 to determine where each isotope should be grouped. An example of this input file is described in Figure 1-1 from line 22 to line 25. It should be noted that this algorithm discriminates the isotopes by their atomic mass which is typically known to 4 significant digits at this point in time.

Table 1.1. VARPOW Atom Mass Based Selection Algorithm

Step 1					
iTypeFuel	1 Zr alloyed	2 Oxide	3 Nitride	4 Al alloyed	
Atom Mass	89.5 – 96.0	15.5 – 18.1	13.9 – 15.1	26.5 – 27.0	
Step 2					
iTypeCool	1 Na	2 NaCl	3 Pb	4 Pb-Bi	5 Sn
Atom Mass	22.5 – 23.0	22.5 – 23.0 38.5 – 41.0	203.5 – 210.0	203.5 – 210.0	111.5 – 124.0
Step 3					
		Structure	Fuel		
Atom Mass		49.0 – 65.0 91.5 – 100.0	Everything Else		

As stated, the Output.VARPOW file is a NHFLUX formatted file which contains the spatial distribution of power density and fast flux. The details of the NHFLUX format can be found elsewhere and no further details are provided here. What does need to be explained is how the 2 or 6 components of the power distribution and the fast flux spatial distribution are stored in a file format that was intended to contain the multi-group spatial flux distribution. VARPOW redefines the NGROUP variable in the NHFLUX file format to be the number of vectors of output. In that regard, the neutron power distribution, gamma power distribution, and fast flux distribution are considered vector outputs. As outlined in Table 1.2, for option M, NGROUP will be set to 3 where “group 1” stores the neutron power distribution, “group 2” stores the gamma power distribution, and “group 3” stores the fast flux distribution. For options S and T, NGROUP is set to 7 and the interpretation of the group storage positions in NHFLUX are interpreted as seen in Table 1.2.

Table 1.2. Output.VARPOW file description based on iOutput parameters

iOutput option M or P		iOutput option S or T	
NGROUP	3	NGROUP	7
Group 1	neutron power distribution	Group 1	neutron power distribution in fuel
Group 2	gamma power distribution	Group 2	neutron power distribution in clad
Group 3	Fast neutron flux	Group 3	neutron power distribution in coolant
		Group 4	gamma power distribution in fuel
		Group 5	gamma power distribution in clad
		Group 6	gamma power distribution in coolant
		Group 7	Fast neutron flux

The 'VariantMonoExponents.out' file is actually produced by many utility programs associated with DIF3D-VARIANT [1]. As stated, this file contains information about the spatial basis in DIF3D-VARIANT and is required information if one evaluates that basis independent of EvaluateFlux [1]. For the VARPOW calculation, this file stores the coefficient matrix to transfer polynomial coefficients to monomials. The verification of the coefficient matrix stored in VariantMonoExponents.out is not doable by hand as it involves a Cholesky matrix factorization or Gram-Schmidt orthogonalization procedure. It also requires knowing the integral of a monomial over the reference space of the domain which is trivial for Cartesian geometries but not so for hexagonal geometries. Therefore, to verify the data stored in 'VariantMonoExponents.out' the expected matrix properties will be checked for a simple test case. The provided information in VariantMonoExponents.out is intended to be used by the end user to evaluate the polynomial-based VARPOW output in Output.VARPOW. The easiest way to do this is to evaluate the monomial basis in the desired fashion and thus convert the polynomial basis into the monomial basis. Consequently, the action of converting between the polynomial and monomial basis will be checked.

The 'MaterialPower.out' file is an ascii file that contains the mesh-wise average power density in a six-component format (fuel, structure, and coolant component breakdown for neutron and gamma heating). Figure 1-2 shows an excerpt from the 'MaterialPower.out' file which has two header lines followed by a large array of values. As the first header line indicates, all of the values provided correspond to power density in units of W/cc. The second header line indicates the array being exported and its dimensions which are defined in the DIF3D manual and NHFLUX file format. The output format is implied to be a dump of a three-dimensional array of size $6 \cdot 271 \cdot 20 = 32520$. The conventional Fortran approach to dumping such arrays is implicitly used where the 6 columns of output correspond to the first dimension (1:6) of the array MatPowerDensity(6,271,20). From line 30 in Figure 1-1, the six columns correspond to fuel (1), structure (2), coolant (3) neutron power density and fuel (4), structure (5), and coolant (6) gamma power density. The NINTXY variable corresponds to the number of radial meshes and the NINTK corresponds to the number of axial meshes. Thus the first 271 lines of data corresponds to the radial mesh power density results for the first axial plane. The next 271 lines after that corresponds to the radial mesh power density results for the second axial plane and so on from there.

```
# This is the VARPOW material power density (watts/cc) for all active meshes
# MatPowerDensity(6,NINTXY,NINTK) NINTXY=   271 NINTK=    20
 8.897002942E-12  1.018543609E-10  1.540309970E-11  3.897528608E-11  2.882721050E-09  5.019429147E-11
 8.632496147E-12  9.870278021E-11  1.492348071E-11  3.784142717E-11  2.798811176E-09  4.873463086E-11
 8.632496147E-12  9.870278018E-11  1.492348071E-11  3.784209270E-11  2.798864118E-09  4.873556236E-11
 8.632496147E-12  9.870278021E-11  1.492348071E-11  3.784142717E-11  2.798811176E-09  4.873463086E-11
 8.632496147E-12  9.870278018E-11  1.492348071E-11  3.784209270E-11  2.798864118E-09  4.873556236E-11
 8.632496147E-12  9.870278021E-11  1.492348071E-11  3.784142717E-11  2.798811176E-09  4.873463086E-11
 8.632496147E-12  9.870278018E-11  1.492348071E-11  3.784209270E-11  2.798864118E-09  4.873556236E-11
 7.876311995E-12  8.941420901E-11  1.351534580E-11  3.458954697E-11  2.558338317E-09  4.454748256E-11
 8.122669280E-12  9.246724918E-11  1.397820479E-11  3.564623369E-11  2.636467591E-09  4.590784977E-11
 7.876311995E-12  8.941420901E-11  1.351534580E-11  3.458964060E-11  2.558345810E-09  4.454761983E-11
 8.122669280E-12  9.246724918E-11  1.397820479E-11  3.564623369E-11  2.636467591E-09  4.590784977E-11
 7.876311995E-12  8.941420901E-11  1.351534580E-11  3.458954697E-11  2.558338317E-09  4.454748256E-11
 8.122669280E-12  9.246724918E-11  1.397820479E-11  3.564623369E-11  2.636467591E-09  4.590784977E-11
 7.876311995E-12  8.941420901E-11  1.351534580E-11  3.458964060E-11  2.558345810E-09  4.454761983E-11
 8.122669280E-12  9.246724918E-11  1.397820479E-11  3.564623369E-11  2.636467591E-09  4.590784977E-11
 7.876311995E-12  8.941420901E-11  1.351534580E-11  3.458954697E-11  2.558338317E-09  4.454748256E-11
 8.122669280E-12  9.246724918E-11  1.397820479E-11  3.564623369E-11  2.636467591E-09  4.590784977E-11
 7.876311995E-12  8.941420901E-11  1.351534580E-11  3.458964060E-11  2.558345810E-09  4.454761983E-11
 8.122669280E-12  9.246724918E-11  1.397820479E-11  3.564623369E-11  2.636467591E-09  4.590784977E-11
 6.714164301E-12  7.501989119E-11  1.133373734E-11  2.958835565E-11  2.188629391E-09  3.810895937E-11
 7.162030971E-12  8.062966282E-11  1.218326262E-11  3.151489631E-11  2.331008793E-09  4.058921116E-11
 7.162030972E-12  8.062966285E-11  1.218326262E-11  3.151453180E-11  2.330979688E-09  4.058869903E-11
 6.714164300E-12  7.501989117E-11  1.133373734E-11  2.958847691E-11  2.188639180E-09  3.810912750E-11
 7.162030972E-12  8.062966285E-11  1.218326262E-11  3.151453180E-11  2.330979688E-09  4.058869903E-11
 7.162030971E-12  8.062966282E-11  1.218326262E-11  3.151489631E-11  2.331008793E-09  4.058921116E-11
 6.714164301E-12  7.501989120E-11  1.133373734E-11  2.958835565E-11  2.188629391E-09  3.810895937E-11
 7.162030971E-12  8.062966282E-11  1.218326262E-11  3.151489631E-11  2.331008793E-09  4.058921116E-11
 7.162030972E-12  8.062966285E-11  1.218326262E-11  3.151453180E-11  2.330979688E-09  4.058869903E-11
 6.714164300E-12  7.501989117E-11  1.133373734E-11  2.958847691E-11  2.188639180E-09  3.810912750E-11
 7.162030972E-12  8.062966285E-11  1.218326262E-11  3.151453180E-11  2.330979688E-09  4.058869903E-11
 7.162030971E-12  8.062966282E-11  1.218326262E-11  3.151489631E-11  2.331008793E-09  4.058921116E-11
 6.714164301E-12  7.501989120E-11  1.133373734E-11  2.958835565E-11  2.188629391E-09  3.810895937E-11
 7.162030971E-12  8.062966282E-11  1.218326262E-11  3.151489631E-11  2.331008793E-09  4.058921116E-11
```

Figure 1-2. Excerpt from example of MaterialPower.out file

From the preceding descriptions, it should be clear that the focus of the verification work is to check the data in files Output.VARPOW and MaterialPower.out. All input options shown in line 5 through line 10 in Figure 1-1 [8] should be verified to produce the expected result. The VARPOW output for the PMATRX input path and the ISOTXS input path should also be checked. To display the work, all of the binary interface files are converted to readable ascii files using the utility code PrintTables.x.

The identified task list for the verification work is shown in Table 1.3 [8], where the category number refers to a specific functional use of the VARPOW software. To satisfy each task, at least one verification problem will need to be identified or created such that it can be regularly executed to verify the GAMSRC/GAMSOR software capabilities.

Table 1.3. VARPOW Identified Verification Tasks

Category	Verification Tasks
1	Verify the terminal output from VARPOW is correct a) Verify the isotope selection adheres to the provided input b) Verify the material power output is correct
2	Verify the Output.VARPOW file is correct a) Verify the power distributions are correct b) Verify the fast flux distribution is correct
3	Verify the VariantMonoExponents.out file is consistent with DIF3D a) Verify the exponents adhere to the polynomial definition in DIF3D b) Verify the monomial to polynomial transformation matrix is correct
4	Verify the MaterialPower.out file is correct a) Verify it uses the same spatial mesh as input DIF3D/GAMSOR case b) Verify that reported power details are correct

2 Methodology of VARPOW

As stated, the intention of VARPOW is for use after GAMSOR (PMATRX) to calculate power distribution details (Output.VARPOW and MaterialPower.out) for follow-on thermal analysis. VARPOW can also use a DIF3D/REBUS (ISOTXS) output for prototyping calculations. VARPOW uses the interface files from GAMSOR or DIF3D/REBUS to define the geometry and compositions along with the cross section data file to compute the power density. To understand how this is done, the equations to evaulate the neutron and gamma power distributions need to be defined.

In this section the equations are provided only for the un-normalized polynomial basis of DIF3D-VARIANT (iOutput option P or T). This can be directly calculated using neutron and gamma flux distributions from DIF3D, the required cross section data, and knowledge of the geometry and compositions. For the normalized monomial basis output (iOutput option M or S), they are checked by applying the polynomial-to-monomial transfer matrix to the polynomial basis result which will be described later.

2.1 VARPOW calculation using GAMSOR

The VARPOW calculation given the GAMSOR output, the preferred approach, is displayed here. When using the three-point output seen in the 'Output.VARPOW' file (iOutput option P), the neutron and gamma power densities are obtained using equations 2-1 and 2-2:

$$\hat{P}^{N}_{i,m} = \sum_{g=1}^{NG} \sum_{iso \in mesh\ i}^{iso} N_{iso,i} \mathrm{K}^{N}_{iso,g} \widehat{\emptyset}_{i,g,m} \qquad 2\text{-}1$$

$$\hat{P}^{G}_{i,m} = \sum_{p=1}^{NP} \sum_{iso \in mesh\ i}^{iso} N_{iso,i} \mathrm{K}^{G}_{iso,p} \hat{\varphi}_{i,p,m} \qquad 2\text{-}2$$

Where : i is the index of the mesh or the unique index into the space (NINTXY,NINTK)

g is the energy group for the neutron flux

NG is the total number of neutron energy groups

p is the energy group for the gamma flux

NP is the total number of gamma energy groups

$N_{iso,i}$ is the atom number density of isotope iso in mesh i.

$\mathrm{K}^{N}_{iso,g}$ is the neutron KERMA factor for isotope iso and energy group g

$\mathrm{K}^{G}_{iso,p}$ is the gamma KERMA factor for isotope iso and energy group p

m is the index of the spatial basis moment of the flux (m=0,1,2,..M)

$\hat{\emptyset}_{i,g,m}$ is the m^{th} neutron scalar flux moment in mesh i for energy group g.

$\hat{\varphi}_{i,p,m}$ is the m^{th} gamma scalar flux moment in mesh i for energy group p.

$\hat{P}^{N}_{i,m}$ is the neutron power density in mesh i for moment m.

$\hat{P}^{G}_{i,m}$ is the gamma power density in mesh i for moment m.

The neutron and gamma KERMA factors are stored in the PMATRX file as isotope-wise microscopic (heating) cross sections. The flux moments are taken from the NHFLUX and GHFLUX files and the atom density information for each mesh requires using GEODST, NDXSRF, and ZNATDN.

The following equation is used to obtain the fast neutron flux where $E > 100$ keV:

$$\hat{\emptyset}^{Fast}_{i,m} = factor \times \hat{\emptyset}_{i,n,m} + \sum_{g=1}^{n-1} \hat{\emptyset}_{i,g,m} \qquad 2\text{-}3$$

In this equation, group n is assumed to have energy boundaries that bound E=100 keV (typical setup of a multi-group library). If the energy boundary is exactly at 100 keV, then this factor is zero. In the general case, the value of "*factor*" is calculated by assuming the neutron flux is linear with lethargy within the energy group n:

$$factor = \left. ln\left(\frac{E_{n-1}}{E_0}\right) \middle/ ln\left(\frac{E_{n-1}}{E_n}\right) \right. \qquad 2\text{-}4$$

Where : n is the neutron energy group bounding 100 keV

E_n is the lower energy boundary of the n^{th} neutron group.

E_0 = 100 keV

This is of course an approximation, but assuming a reasonable number of energy groups and neutron spectrum, this particular group will not dominate the fast flux result.

When using the seven vector output in 'Output.VARPOW' (iOutput option T), the neutron and gamma power densities are calculated in a very similar way to the three vector output case. The primary difference is that the isotopes are categorized into three components (fuel, structure, coolant), as shown in equations 2-5 and 2-6.

$$\hat{P}^{N,j}_{i,m} = \sum_{g=1}^{NG} \sum_{\substack{iso \in mesh\ i, \\ iso \in component\ j}}^{iso} N_{iso,i} K^{N}_{iso,g} \hat{\emptyset}_{i,g,m} \qquad 2\text{-}5$$

$$\hat{P}_{i,m}^{G,j} = \sum_{p=1}^{NP} \sum_{\substack{iso \in mesh\ i \\ iso \in component\ j}}^{iso} N_{iso,i} K_{iso,p}^{G} \hat{\varphi}_{i,p,m} \qquad 2\text{-}6$$

Where : *component 1* is for isotopes categorized to the fuel

component 2 is for isotopes categorized to the structure

component 3 is for isotopes categorized to the coolant

$\hat{P}_{i,m}^{N,j}$ is the neutron power density in mesh *i* for moment *m* in component *j*.

$\hat{P}_{i,m}^{G}$ is the gamma power density in mesh *i* for moment *m* in component *j*.

For the data in MaterialPower.out, the six values for each mesh correspond to the neutron and gamma power densities calculated using equations 2-5 and 2-6 for just the first moment which in DIF3D-VARIANT is the mesh averaged flux for a given mesh and group.

2.2 VARPOW calculation using DIF3D

The VARPOW calculation given the ISOTXS input, for rapid prototyping, is displayed here. The gamma flux file GHFLUX is of not available nor needed. The layout of Output.VARPOW and MaterialPower.out are identical to those for GAMSOR but all of the gamma power densities are set to zero. The fast neutron flux is calculated using the same equations 2-3 and 2-4 and no further details are given here.

When using the three vector output in Output.VARPOW (iOutput option P), the second point of data which corresponds to gamma power is set to zero. The neutron power density is calculated using:

$$\hat{P}_{i,m}^{N} = \sum_{g=1}^{NG} \sum_{iso}^{iso \in mesh\ i} N_{iso,i} \left(Q_{iso}^{cap} \sigma_{iso,g}^{cap} + Q_{iso}^{fis} \sigma_{iso,g}^{fis} \right) \hat{\emptyset}_{i,g,m} \qquad 2\text{-}7$$

Where : i is the index of the mesh or the unique index into space (NINTXY,NINTK)

g is the energy group for the neutron flux

NG is the total number of neutron energy groups

$N_{iso,i}$ is the atom number density of isotope *iso* in mesh *i*.

Q_{iso}^{cap} is the neutron capture power yield for isotope *iso*

Q_{iso}^{fis} is the neutron fission power yield for isotope *iso*

$\sigma_{iso,g}^{cap}$ is the capture cross section of isotope *iso*, at energy group *g*

$\sigma_{iso,g}^{fis}$ is the fission cross section of isotope *iso*, at energy group *g*

m is the index of the spatial flux moment (*m*=0,1,2,..M)

$\widehat{\emptyset}_{i,g,m}$ is the m^{th} neutron flux moment in mesh *i* for energy group *g*

$\hat{P}_{i,m}^{N}$ is the neutron power density in mesh *i* for moment *m*

The cross section data Q_{iso}^{cap}, Q_{iso}^{fis} and $\sigma_{iso,g}^{fis}$ are all provided in the ISOTXS file directly. Both Q_{iso}^{cap} and Q_{iso}^{fis} are referred to as thermal energy yield and have units of watts/reaction_rate and thus it is referred to as power yield here to avoid confusion with the neutron/gamma energy. The neutron capture cross section $\sigma_{iso,g}^{cap}$ is not explicitly stored in the ISOTXS file. Instead it needs to be calculated as the summation of the partial cross sections that are stored in ISOTXS:

$$\sigma_{iso,g}^{cap} = \sigma_{iso,g}^{(n,\gamma)} + \sigma_{iso,g}^{(n,\alpha)} + \sigma_{iso,g}^{(n,p)} + \sigma_{iso,g}^{(n,d)} + \sigma_{iso,g}^{(n,t)} \qquad 2\text{-}8$$

The term $\left(Q_{iso}^{cap}\sigma_{iso,g}^{cap} + Q_{iso}^{fis}\sigma_{iso,g}^{fis}\right)$ is conceptually similar to the KERMA microscopic cross section values from the preceding PMATRIX input pathway discussion although the conversion factor from eV to Joules is needed because the KERMA cross section definitions in PMATRX are eV/barn.

For the seven vector output in Output.VARPOW (iOutput option P), the 4th through 6th vector data, corresponding to the three gamma power components, are all set to zero. The neutron power density is calculated as shown in equation 2-9.

$$\hat{P}_{i,m}^{N,j} = \sum_{g=1}^{G} \sum_{\substack{iso \in mesh\ i \\ iso \in component\ j}}^{} N_{iso,i}\left(Q_{iso}^{cap}\sigma_{iso,g}^{cap} + Q_{iso}^{fis}\sigma_{iso,g}^{fis}\right)\widehat{\emptyset}_{i,g,m} \qquad 2\text{-}9$$

Where : *class 1* is for isotopes categorized to the fuel

class 2 is for isotopes categorized to the structure

class 3 is for isotopes categorized to the coolant

$\hat{P}_{i,m}^{N,j}$ is the neutron power density in mesh *i* for moment *m* in component *j*

The data format of MaterialPower.out does not change when using ISOTXS or PMATRIX, but for the former, only the first 3 columns will have non-zero data. The neutron power densities are calculated using equation 2-9 but the output in MaterialPower.out corresponds to just the first moment which is the mesh-averaged flux moment in DIF3D-VARIANT.

2.3 Monomial based output of VARPOW

The equations shown in the previous sections are for the polynomial based power densities (iOutput option P or T). As discussed, for some follow-on applications having a normalized monomial basis combined with the mesh-averaged power density information in MaterialPower.out is preferred. This is the purpose of iOutput options M and S. When either of these two options is used, the VARPOW calculation follows the same methodology as option P or T to obtain the power density and fast flux distribution. An additional step is simply added at the end to normalize the spatial distribution by mesh and convert the polynomial coefficients into monomial ones (using the coefficient matrix stored in file VariantMonoExponents.out). Note that the coefficient matrix is only be printed in VariantMonoExponents.out when iOutput option P or T is used as it is unnecessary when given a monomial basis. Also, when using iOutput M or S options, the fast neutron flux stored in 'Output.VARPOW' file is not normalized but is converted into the monomial basis.

The normalized data in a monomial basis can be calculated using:

$$Norm\_Mono_j = \left(\sum_{m=0}^{M} \hat{F}_{j,m} Poly_m\right) \Big/ Poly_0 \qquad 2\text{-}10$$

The un-normalized data in a monomial basis can be calculated using:

$$Un\_Norm\_Mono_j = \left(\sum_{m=0}^{M} \hat{F}_{j,m} Poly_m\right) \qquad 2\text{-}11$$

Where : m=0, 1, 2,.. M is the moment index for the spatial polynomials coefficient
$Poly_m$ is the m^{th} moment of the spatial polynomial coefficients
$Poly_0$ is the first moment of the spatial polynomial coefficients
j is the moment index for the spatial monomial coefficients
$Mono_j$ is j^{th} the monomial-based data
$\hat{F}_{j,m}$ is the value at the j^{th} row and m^{th} column of the coefficient matrix

3 Verification of VARPOW

In this section, a few benchmark problems are displayed which are used to verify the VARPOW software. The benchmark problems include simple problems which can be confirmed with hand calculations as well as some larger problems that represent actual use cases. It should be noted that in this section, GAMSRC is used instead of GAMSOR which has been shown to be an equivalent capability to GAMSOR [12].

3.1 Simple 2D Quarter Core Model for VARPOW Verification

The first test case is a simple two-dimensional Cartesian geometry model shown in Figure 3-1 and is benchmark #17 in the verification test suite. The left and bottom boundary conditions are reflected while the upper and right hand side boundaries are vacuum indicating that this is one quarter of the true geometry. The DIF3D model consists of 16 meshes in a 4 x 4 grid with just 3 compositions (zones in DIF3D nomenclature). A 4 group structure is used for the neutron cross sections and 21 groups for the gamma cross sections. Table 3.1 summarizes the iTypeFuel, iTypeCoolant, and iOutput options tested using this case. The GAMSOR input path, preferred by VARPOW, is examined thoroughly while the DIF3D routine is only considered in a few cases.

In this section, the test cases do not use the AssignIsotope.inp file which allows the user to directly define isotopes as fuel, structure, and coolant. After running these test cases, it was found that the iTypeCool=2 option does not work as intended as the Cl-35 isotope is put into the fuel material. It is easy to see why this occurs given the atom mass based algorithm of VARPOW shown earlier in Table 1.1. In addition to this, the iTypeCool=5 option is not presently working in VARPOW and results in a fatal error message. Therefore no test cases for it are included in Table 3.1. Finally the options iTypeCool=3 and iTypeCool=4 are the same for the isotope classification as both isotopes Pb-208 and Bi-209 are always assigned to the coolant when using either of these two options. These issues impact the verification work that is to be carried out on VARPOW but they are not considered vital as the AssignIsotope.inp file can be used to completely negate the importance of these input flags.

As discussed earlier, the iOutput option P and T will provide polynomial-based power distribution. These can easily be reproduced by external calculation (hand calculation or a simple program) given the neutron and gamma flux moments calculated by GAMSOR. For this reason the power density is the primary verification task. The normalized monomial power density output (iOutput option M or S) are verified for a few cases.

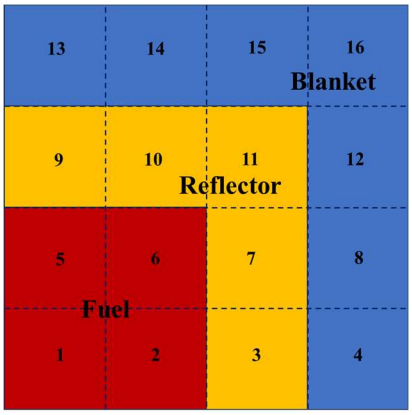

Figure 3-1. Configuration of the Simple Two-dimensional Model (Quarter Core Symmetry)

Table 3.1. VARPOW Test Cases for the Simple Two-dimensional Model

Routine	(iTypeFuel) Fuel	(iTypeCool) Coolant	iOutput
DIF3D	(2) Oxide	(1) Na	M P S T
GAMSOR	(1) Zr-alloyed	(1) Na	P T
	(2) Oxide	(1) Na	M P S T
		(2) NaCl	P T
		(3) Pb	P T
		(4) Pb-Bi	P T
		(5) Sn	P T
	(3) Nitride	(1) Na	P T
	(4) Alum Alloyed	(1) Na	P T

For all of the test cases, only 10 isotopes are used noting that each individual test case might only have some of those. For these 10 isotopes, the 4 group neutron and 21 group gamma heating KERMA heating cross sections were obtained by using the PrintTables utility program to display the PMATRX library. An excerpt of the output is shown in Figure 3-2. The PrintTables utility program was also used to display the ISOTXS file which contains the microscopic cross section data for these isotopes. An excerpt of the ISOTXS output for two isotopes is shown in Figure 3-3. It should be clear that even with just 10 isotopes, the full ISOTXS or PMATRX data cannot easily be fully displayed in this manuscript. In all of these cases a companion Excel document is available which demonstrates how to take either the PMATRX or ISOTXS based cross section data and get the output produced by VARPOW. Those Excel spreadsheets also cover how to calculate the macroscopic cross section data that follows. Using the PrintTables output, the data needed for the hand calculation for the GAMSOR path (i.e. the PMATRX file) was collected for the 10 isotopes and the relevant data is put into Table 3.2 and Table 3.3. A quick comparison of Figure 3-2 to these two tables should clearly indicate that it is a faithful translation of the output.

```
[PMATRX]...Neutron Heating
[PMATRX]...Isotope ->     NA23I         FE56I         U235I         U238I         P239I         O16_I         CL35I      ...
[PMATRX]...       1    1.269488E+05  5.062149E+04  2.137464E+08  1.001495E+07  2.797132E+08  2.060940E+05  1.514052E+05...
[PMATRX]...       2    1.654669E+04  7.037442E+03  3.473713E+08  1.451243E+04  2.885615E+08  2.142682E+04  5.701133E+03...
[PMATRX]...       3    3.198666E+02  4.859424E+02  1.436093E+09  2.768228E+05  1.038567E+09  4.403129E+02  2.328972E+02...
[PMATRX]...       4    1.583902E+02  2.106849E+02  2.133737E+09  6.633947E+05  1.376670E+09  2.498027E+02  6.084570E+04...
....
[PMATRX]...Gamma Heating
[PMATRX]...Isotope ->     NA23I         FE56I         U235I         U238I         P239I         O16_I         CL35I      ...
[PMATRX]...       1    7.986170E+06  3.017550E+07  2.522880E+08  2.522880E+08  2.609210E+08  5.099300E+06  1.533200E+07...
[PMATRX]...       2    5.638980E+06  1.926460E+07  1.486240E+08  1.486240E+08  1.536870E+08  3.732710E+06  1.028010E+07...
[PMATRX]...       3    4.784870E+06  1.548270E+07  1.141770E+08  1.141770E+08  1.181060E+08  3.222780E+06  8.492260E+06...
[PMATRX]...       4    4.220920E+06  1.307740E+07  9.279220E+07  9.279220E+07  9.601630E+07  2.880190E+06  7.336810E+06...
[PMATRX]...       5    3.667150E+06  1.081060E+07  7.309180E+07  7.309180E+07  7.570590E+07  2.537400E+06  6.227070E+06...
[PMATRX]...       6    3.121950E+06  8.703980E+06  5.530050E+07  5.530050E+07  5.735960E+07  2.191900E+06  5.168600E+06...
[PMATRX]...       7    2.574890E+06  6.758210E+06  3.983830E+07  3.983830E+07  4.140420E+07  1.834480E+06  4.151670E+06...
[PMATRX]...       8    2.166790E+06  5.437460E+06  3.023670E+07  3.023670E+07  3.150040E+07  1.559110E+06  3.427740E+06...
[PMATRX]...       9    1.874350E+06  4.582090E+06  2.483910E+07  2.483910E+07  2.594680E+07  1.356340E+06  2.933290E+06...
[PMATRX]...      10    1.560400E+06  3.744160E+06  2.072950E+07  2.072950E+07  2.175700E+07  1.133650E+06  2.423160E+06...
[PMATRX]...      11    1.205010E+06  2.877610E+06  1.887060E+07  1.887060E+07  1.999290E+07  8.766940E+05  1.866300E+06...
[PMATRX]...      12    8.808150E+05  2.121350E+06  2.009100E+07  2.009100E+07  2.154850E+07  6.407410E+05  1.365870E+06...
[PMATRX]...      13    6.122210E+05  1.514800E+06  2.555060E+07  2.555060E+07  2.766180E+07  4.450380E+05  9.539360E+05...
[PMATRX]...      14    3.982450E+05  1.077840E+06  3.953490E+07  3.953490E+07  4.292870E+07  2.885900E+05  6.313180E+05...
[PMATRX]...      15    2.208910E+05  9.382770E+05  8.780240E+07  8.780240E+07  9.476360E+07  1.567590E+05  3.909620E+05...
[PMATRX]...      16    1.258490E+05  1.515860E+06  1.307010E+08  1.307010E+08  1.198060E+08  7.908950E+04  3.450320E+05...
[PMATRX]...      17    1.126120E+05  2.625520E+06  7.955010E+07  7.955010E+07  8.760340E+07  5.653130E+04  4.733330E+05...
[PMATRX]...      18    1.523400E+05  5.398600E+06  1.475020E+08  1.475020E+08  1.617320E+08  5.250650E+04  8.994200E+05...
[PMATRX]...      19    3.507140E+05  1.379080E+07  3.227690E+08  3.227690E+08  3.515590E+08  8.920340E+04  2.342280E+06...
[PMATRX]...      20    8.235550E+05  3.013380E+07  5.853110E+08  5.853110E+08  6.013490E+08  2.003260E+05  5.399080E+06...
[PMATRX]...      21    3.210080E+06  8.411990E+07  5.539970E+08  5.539970E+08  5.568750E+08  8.195810E+05  1.899410E+07...
```

Figure 3-2. Output Excerpt of PrintTables Dump of PMATRX Library

With regard to Figure 3-3, the ISOTXS based KERMA cross section defined earlier as $\left(Q_{iso}^{cap}\sigma_{iso,g}^{cap} + Q_{iso}^{fis}\sigma_{iso,g}^{fis}\right)$ can be calculated from the displayed data for the isotopes shown. The calculated microscopic neutron KERMA cross section from the ISOTXS file are listed in Table 3.4, where the conversion from Joule to eV was applied to obtain cross sections similar to those provided in Table 3.2. Because the test case using DIF3D routine in Table 3.1 only uses 6 isotopes, the cross sections for only those 6 isotopes are shown in Table 3.2. For the first group of the Fe-56 cross section output, one sums the partial cross sections 4.00086E-3 + 6.531439E-5 + 1.52985E-4 + 2.326701E-7 + 4.83922E-11 from Figure 3-3 to get a capture cross section of 4.21939E-3. This is multiplied by the yield/capture value from Figure 3-3 for Fe-56 of 0.122498E-11 and divided by the conversion factor 1.6022E-19 Joule/eV to obtain 3.22603E+4 eV·barn. This result is consistent with the 3.226031E+04 value in Table 3.4. No additional verification of the heating cross section calculation from ISOTXS is provided here but it is important to see that the heating cross sections from PMATRX and those derived from ISOTXS are not the same.

```
.....
[ISOTXS]...FILEWIDE ISOTOPE LABEL.....                                        FE56I
.....
[ISOTXS]...TOTAL THERMAL ENERGY YIELD/FISSION (W.SEC/FISS)..... 0.000000000E+00
[ISOTXS]...TOTAL THERMAL ENERGY YIELD/CAPTURE (W.SEC/CAPT)..... 0.122498008E-11
.....
[ISOTXS]...GROUP   TRANS(P1)     TOTAL (P0)     (N,GAMMA)      FISSION      YIELD/FISS       CHI      .............
[ISOTXS]...     1  2.101999E+00  2.747668E+00  4.000860E-03  0.000000E+00  0.000000E+00  0.000000E+00 .............
[ISOTXS]...     2  3.163577E+00  4.191343E+00  6.885688E-03  0.000000E+00  0.000000E+00  0.000000E+00 .............
[ISOTXS]...     3  9.388939E+00  9.652336E+00  2.570307E-01  0.000000E+00  0.000000E+00  0.000000E+00 .............
[ISOTXS]...     4  1.009644E+01  1.023497E+01  1.217358E-02  0.000000E+00  0.000000E+00  0.000000E+00 .............
.....
[ISOTXS]...GROUP    (N,ALPHA)      (N,PROTON)       (N,2N)     (N,DEUTERON)  (N,TRITIUM)       ZERO      .............
[ISOTXS]...     1  6.531439E-05  1.529857E-04  8.604657E-06  2.326701E-07  4.839220E-11  0.000000E+00 .............
[ISOTXS]...     2  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 .............
[ISOTXS]...     3  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 .............
[ISOTXS]...     4  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 .............
.....
.....
[ISOTXS]...FILEWIDE ISOTOPE LABEL.....                                        U235I
.....
[ISOTXS]...TOTAL THERMAL ENERGY YIELD/FISSION (W.SEC/FISS)..... 0.309979091E-10
[ISOTXS]...TOTAL THERMAL ENERGY YIELD/CAPTURE (W.SEC/CAPT)..... 0.104860641E-11
.....
[ISOTXS]...GROUP   TRANS(P1)     TOTAL (P0)     (N,GAMMA)      FISSION      YIELD/FISS       CHI      .............
[ISOTXS]...     1  6.966056E+00  9.145856E+00  2.122510E-01  1.264427E+00  2.505877E+00  9.858797E-01 .............
[ISOTXS]...     2  1.275115E+01  1.358605E+01  6.642796E-01  2.052441E+00  2.429491E+00  1.410348E-02 .............
[ISOTXS]...     3  2.495927E+01  2.502641E+01  4.503449E+00  8.553695E+00  2.433800E+00  8.886566E-06 .............
[ISOTXS]...     4  2.959821E+01  2.975079E+01  5.344621E+00  1.251864E+01  2.433805E+00  7.954162E-06 .............
.....
[ISOTXS]...GROUP    (N,ALPHA)      (N,PROTON)       (N,2N)     (N,DEUTERON)  (N,TRITIUM)       ZERO      .............
[ISOTXS]...     1  0.000000E+00  0.000000E+00  1.792770E-03  0.000000E+00  0.000000E+00  0.000000E+00 .............
[ISOTXS]...     2  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 .............
[ISOTXS]...     3  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 .............
[ISOTXS]...     4  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00 .............
.....
```

Figure 3-3. Output Excerpt of PrintTables Dump of ISOTXS Library

Table 3.2. PMATRX Based Neutron Heating Microscopic Cross Section (unit eV·barn)

group	Na23	Fe56	U235	U238	Pu239	O16	Cl35	Pb208	Bi209	Sn120
1	1.269488E+05	5.062149E+04	2.137464E+08	1.001495E+07	2.797132E+08	2.060940E+05	1.514052E+05	4.847068E+04	2.848293E+04	4.950568E+05
2	1.654669E+04	7.037442E+03	3.473713E+08	1.451243E+04	2.885615E+08	2.142682E+04	5.701133E+03	5.761744E+03	5.087171E+03	2.431290E+05
3	3.198666E+02	4.859424E+02	1.436093E+09	2.768228E+05	1.038567E+09	4.403129E+02	2.328972E+02	1.118082E+02	2.699593E+02	3.199235E+06
4	1.583902E+02	2.106849E+02	2.133737E+09	6.633947E+05	1.376670E+09	2.498027E+02	6.084570E+04	6.351244E+01	3.826851E+01	9.197465E+05

Table 3.3. PMATRX Based Gamma Heating Microscopic Cross Section (unit eV·barn)

group	Na23	Fe56	U235	U238	Pu239	O16	Cl35	Pb208	Bi209	Sn120
1	7.986170E+06	3.017550E+07	2.522880E+08	2.522880E+08	2.609210E+08	5.099300E+06	1.533200E+07	2.090780E+08	2.133280E+08	9.049370E+07
2	5.638980E+06	1.926460E+07	1.486240E+08	1.486240E+08	1.536870E+08	3.732710E+06	1.028010E+07	1.232240E+08	1.257320E+08	5.433820E+07
3	4.784870E+06	1.548270E+07	1.141770E+08	1.141770E+08	1.181060E+08	3.222780E+06	8.492260E+06	9.461530E+07	9.655530E+07	4.216020E+07
4	4.220920E+06	1.307740E+07	9.279220E+07	9.279220E+07	9.601630E+07	2.880190E+06	7.336810E+06	7.680630E+07	7.838420E+07	3.454640E+07
5	3.667150E+06	1.081060E+07	7.309180E+07	7.309180E+07	7.570590E+07	2.537400E+06	6.227070E+06	6.038160E+07	6.161750E+07	2.749950E+07
6	3.121950E+06	8.703980E+06	5.530050E+07	5.530050E+07	5.735960E+07	2.191900E+06	5.168600E+06	4.552540E+07	4.646590E+07	2.109950E+07
7	2.574890E+06	6.758210E+06	3.983830E+07	3.983830E+07	4.140420E+07	1.834480E+06	4.151670E+06	3.259690E+07	3.328500E+07	1.541240E+07
8	2.166790E+06	5.437460E+06	3.023670E+07	3.023670E+07	3.150040E+07	1.559110E+06	3.427740E+06	2.452350E+07	2.505630E+07	1.178130E+07
9	1.874350E+06	4.582090E+06	2.483910E+07	2.483910E+07	2.594680E+07	1.356340E+06	2.933290E+06	1.994330E+07	2.038950E+07	9.619950E+06
10	1.560400E+06	3.744160E+06	2.072950E+07	2.072950E+07	2.175700E+07	1.133650E+06	2.423160E+06	1.632630E+07	1.672310E+07	7.715190E+06
11	1.205010E+06	2.877610E+06	1.887060E+07	1.887060E+07	1.999290E+07	8.766940E+05	1.866300E+06	1.420430E+07	1.461080E+07	6.043300E+06
12	8.808150E+05	2.121350E+06	2.009100E+07	2.009100E+07	2.154850E+07	6.407410E+05	1.365870E+06	1.413670E+07	1.464160E+07	4.820660E+06
13	6.122210E+05	1.514800E+06	2.555060E+07	2.555060E+07	2.766180E+07	4.450380E+05	9.539360E+05	1.693950E+07	1.766740E+07	4.168430E+06
14	3.982450E+05	1.077840E+06	3.953490E+07	3.953490E+07	4.292870E+07	2.885900E+05	6.313180E+05	2.547510E+07	2.667610E+07	4.501690E+06
15	2.208910E+05	9.382770E+05	8.780240E+07	8.780240E+07	9.476360E+07	1.567590E+05	3.909620E+05	5.743980E+07	6.008630E+07	8.526540E+06
16	1.258490E+05	1.515860E+06	1.307010E+08	1.307010E+08	1.198060E+08	7.908950E+04	3.450320E+05	1.334200E+08	1.391040E+08	2.068100E+07
17	1.126120E+05	2.625520E+06	7.955010E+07	7.955010E+07	8.760340E+07	5.653130E+04	4.733330E+05	1.318830E+08	1.190370E+08	3.698890E+07
18	1.523400E+05	5.398600E+06	1.475020E+08	1.475020E+08	1.617320E+08	5.250650E+04	8.994200E+05	8.954140E+07	9.439640E+07	7.180920E+07
19	3.507140E+05	1.379080E+07	3.227690E+08	3.227690E+08	3.515590E+08	8.920340E+04	2.342280E+06	2.017160E+08	2.120980E+08	1.626030E+08
20	8.235550E+05	3.013380E+07	5.853110E+08	5.853110E+08	6.013490E+08	2.003260E+05	5.399080E+06	3.955240E+08	4.147100E+08	7.520150E+07
21	3.210080E+06	8.411990E+07	5.539970E+08	5.539970E+08	5.568750E+08	8.195810E+05	1.899410E+07	6.170210E+08	6.185970E+08	1.587360E+08

Table 3.4. ISOTXS Based Neutron Heating Microscopic Cross Section (unit : eV·barn)

group	Na23	Fe56	U235	U238	Pu239	O16
1	6.067530E+03	3.226031E+04	2.460226E+08	1.198451E+07	3.183324E+08	4.910842E+03
2	6.442415E+03	5.264607E+04	4.014411E+08	1.749660E+06	3.294749E+08	6.982858E-01
3	4.608029E+04	1.965186E+06	1.684390E+09	6.817182E+06	1.149130E+09	3.940707E+00
4	3.958743E+04	9.307584E+04	2.457008E+09	7.728819E+06	1.529580E+09	5.351145E+00

3.1.1 Test Case with Oxide Fuel and Sodium Coolant

The first case considered has oxide fuel and sodium coolant which requires the iTypeFuel=2 and iTypeCool=1 input options to VARPOW. The isotopic composition of the three zones for this test case are shown in Table 3.5 where the microscopic cross section data has already been shown in Table 3.2 through Table 3.4. For this test, the 6 isotopes were found to be categorized correctly by VARPOW as:

- Pu-239, U-235, U-238 and O-16 are fuel isotopes
- Fe-56 is a structural (clad) isotope
- Na-23 is coolant isotope

To facilitate a hand calculation, the homogeneous (3 vector data in the output.VARPOW file) and 3 material (for MaterialPower.out file data and the 7 vector data in the output.VARPOW file) macroscopic cross sections are displayed in Table 3.6 to Table 3.9. The macroscopic cross section for the Reflector region in Figure 3-1 is reproduced for group 1 here. The Na-23 atom density of 5.0E-3 and Fe-56 atom density of 7.0E-2 from Table 3.5 are combined with the neutron heating cross section values from Table 3.2 of 1.269488E+05 and 5.062149E+04 to get 5.0E-3·1.269488E+05 + 7.0E-2·5.062149E+04 = 4.1782483E+3 which is consistent with the 4.178248E+03 result in Table 3.6. For the 7 vector data output in Table 3.8, the two values are simply not added together leading to 6.34744E+2 (coolant) and 3.54350E+3 (structure) which are consistent with the values in Table 3.8. The remaining calculation of the macroscopic cross sections is not included here for brevity but can be found in the companion Excel documents.

The macroscopic cross section in Table 3.6 or Table 3.7 are used to obtain the three vector data in the Output.VARPOW file (iOutput option M or P). Similarly, the macroscopic cross section data in Table 3.8 and Table 3.9 are used to obtain the seven vector data (fuel, structure and coolant for both neutron and gamma) in the 'Output.VARPOW' file (iOutput option S or T). It should be noted that the power density output in Output.VARPOW is in W/cm^3 and the fast flux has units of $n/cm^2/s$ and no addition details on these units will be given in the remainder of this document. For a VARPOW calculation using the GAMSOR input, it will generate the PMATRX based macroscopic cross section data shown in Table 3.6 and Table 3.8. For the VARPOW calculation using the ISOTXS input path, it will produce the macroscopic cross section data shown in Table 3.7 and Table 3.9.

Table 3.5. Oxide Fuel, Sodium Coolant, Fuel, Reflector, Blanket Atom Densities

Zone name	Atom number density (barn^{-1}/cm)					
	Pu-239	U-235	U-238	O-16	Na-23	Fe-56
Fuel	1.5000E-03	1.2000E-04	5.4000E-03	1.4040E-02	1.1000E-02	1.8000E-02
Reflector					5.0000E-03	7.0000E-02
Blanket		1.0700E-04	1.5000E-02		7.0000E-03	1.7000E-02

Table 3.6. PMATRIX Based Macroscopic Heating Cross Section (eV/cm)

particle	group	Fuel zone	Reflector zone	Blanket zone
Neutron	1	5.045013E+05	4.178248E+03	1.748443E+05
	2	4.752147E+05	5.753544E+02	3.762188E+04
	3	1.731695E+06	3.561530E+01	1.578248E+05
	4	2.324645E+06	1.553989E+01	2.382655E+05
Gamma	1	2.486612E+06	2.152216E+06	4.380202E+06
	2	1.512134E+06	1.376717E+06	2.612234E+06
	3	1.183986E+06	1.107713E+06	2.021572E+06
	4	9.784986E+05	9.365226E+05	1.653674E+06
	5	7.875801E+05	7.750778E+05	1.313648E+06
	6	6.130855E+05	6.248884E+05	1.005246E+06
	7	4.577414E+05	4.859492E+05	7.347510E+05
	8	3.577561E+05	3.914562E+05	5.643902E+05
	9	2.981705E+05	3.301181E+05	4.662603E+05
	10	2.475381E+05	2.698932E+05	3.877341E+05
	11	2.115159E+05	2.074578E+05	3.424326E+05
	12	2.000943E+05	1.528986E+05	3.457434E+05
	13	2.227812E+05	1.090971E+05	4.160301E+05
	14	3.104593E+05	7.744003E+04	6.183647E+05
	15	6.483343E+05	6.678385E+04	1.343928E+06
	16	9.309588E+05	1.067394E+05	2.001151E+06
	17	6.198134E+05	1.843495E+05	1.247185E+06
	18	1.156397E+06	3.786637E+05	2.321155E+06
	19	2.562368E+06	9.671096E+05	5.112970E+06
	20	4.687220E+06	2.113484E+06	9.360333E+06
	21	5.454352E+06	5.904443E+06	9.821742E+06

Table 3.7. ISOTXS Based Macroscopic Neutron Heating Cross Section (eV/cm)

group	Fuel zone	Reflector zone	Blanket zone
1	5.724540E+05	2.288560E+03	2.066830E+05
2	5.528519E+05	3.717437E+03	7.013918E+04
3	1.998515E+06	1.377934E+05	3.162182E+05
4	2.633057E+06	6.713246E+03	3.806915E+05

Table 3.8. PMATRIX Based Component Macroscopic Heating Cross Section (eV/cm)

particle	group	Fuel zone			Reflector zone			Blanket zone		
		fuel	cladding	coolant	fuel	cladding	coolant	fuel	cladding	coolant
neutron	1	5.021937E+05	9.111868E+02	1.396437E+03	0.000000E+00	3.543504E+03	6.347440E+02	1.730951E+05	8.605653E+02	8.886416E+02
	2	4.749060E+05	1.266740E+02	1.820136E+02	0.000000E+00	4.926209E+02	8.273345E+01	3.738642E+04	1.196365E+02	1.158268E+02
	3	1.731683E+06	8.746963E+00	3.518533E+00	0.000000E+00	3.401597E+01	1.599333E+00	1.578143E+05	8.261021E+00	2.239066E+00
	4	2.324639E+06	3.792328E+00	1.742292E+00	0.000000E+00	1.474794E+01	7.919510E-01	2.382608E+05	3.581643E+00	1.108731E+00
gamma	1	1.855605E+06	5.431590E+05	8.784787E+04	0.000000E+00	2.112285E+06	3.993085E+04	3.811315E+06	5.129835E+05	5.590319E+04
	2	1.103342E+06	3.467628E+05	6.202878E+04	0.000000E+00	1.348522E+06	2.819490E+04	2.245263E+06	3.274982E+05	3.947286E+04
	3	8.526639E+05	2.786886E+05	5.263357E+04	0.000000E+00	1.083789E+06	2.392435E+04	1.724872E+06	2.632059E+05	3.349409E+04
	4	6.966753E+05	2.353932E+05	4.643012E+04	0.000000E+00	9.154180E+05	2.110460E+04	1.401812E+06	2.223158E+05	2.954644E+04
	5	5.526507E+05	1.945908E+05	4.033865E+04	0.000000E+00	7.567420E+05	1.833575E+04	1.104198E+06	1.837802E+05	2.567005E+04
	6	4.220724E+05	1.566716E+05	3.434145E+04	0.000000E+00	6.092786E+05	1.560975E+04	8.354247E+05	1.479677E+05	2.185365E+04
	7	3.077698E+05	1.216478E+05	2.832379E+04	0.000000E+00	4.730747E+05	1.287445E+04	6.018372E+05	1.148896E+05	1.802423E+04
	8	2.360471E+05	9.787428E+04	2.383469E+04	0.000000E+00	3.806222E+05	1.083395E+04	4.567858E+05	9.243682E+04	1.516753E+04
	9	1.950750E+05	8.247762E+04	2.061785E+04	0.000000E+00	3.207463E+05	9.371750E+03	3.752443E+05	7.789553E+04	1.312045E+04
	10	1.629788E+05	6.739488E+04	1.716440E+04	0.000000E+00	2.620912E+05	7.802000E+03	3.131606E+05	6.365072E+04	1.092280E+04
	11	1.464638E+05	5.179698E+04	1.325511E+04	0.000000E+00	2.014327E+05	6.025050E+03	2.850782E+05	4.891937E+04	8.435070E+03
	12	1.522211E+05	3.818430E+04	9.688965E+03	0.000000E+00	1.484945E+05	4.404075E+03	3.035147E+05	3.606295E+04	6.165705E+03
	13	1.887803E+05	2.726640E+04	6.734431E+03	0.000000E+00	1.060360E+05	3.061105E+03	3.859929E+05	2.575160E+04	4.285547E+03
	14	2.866775E+05	1.940112E+04	4.380695E+03	0.000000E+00	7.544880E+04	1.991225E+03	5.972537E+05	1.832328E+04	2.787715E+03
	15	6.290155E+05	1.688899E+04	2.429801E+03	0.000000E+00	6.567939E+04	1.104455E+03	1.326431E+06	1.595071E+04	1.546237E+03
	16	9.022889E+05	2.728548E+04	1.384339E+03	0.000000E+00	1.061102E+05	6.292450E+02	1.974500E+06	2.576962E+04	8.809430E+02
	17	5.713154E+05	4.725936E+04	1.238732E+03	0.000000E+00	1.837864E+05	5.630600E+02	1.201763E+06	4.463384E+04	7.882840E+02
	18	1.057546E+06	9.717480E+04	1.675740E+03	0.000000E+00	3.779020E+05	7.617000E+02	2.228313E+06	9.177620E+04	1.066380E+03
	19	2.310276E+06	2.482344E+05	3.857854E+03	0.000000E+00	9.653560E+05	1.753570E+03	4.876071E+06	2.344436E+05	2.454998E+03
	20	4.135753E+06	5.424084E+05	9.059105E+03	0.000000E+00	2.109366E+06	4.117775E+03	8.842293E+06	5.122746E+05	5.764885E+03
	21	3.904883E+06	1.514158E+06	3.531088E+04	0.000000E+00	5.888393E+06	1.605040E+04	8.369233E+06	1.430038E+06	2.247056E+04

Table 3.9. ISOTXS Based Component Macroscopic Heating Cross Section (eV/cm)

group	Fuel Zone			Reflector Zone			Blanket Zone		
	fuel	cladding	coolant	fuel	cladding	coolant	fuel	cladding	coolant
1	5.718066E+05	5.806857E+02	6.674283E+01	0.000000E+00	2.258222E+03	3.033765E+01	2.060921E+05	5.484253E+02	4.247271E+01
2	5.518334E+05	9.476293E+02	7.086657E+01	0.000000E+00	3.685225E+03	3.221208E+01	6.919910E+04	8.949832E+02	4.509691E+01
3	1.962635E+06	3.537335E+04	5.068832E+02	0.000000E+00	1.375630E+05	2.304015E+02	2.824874E+05	3.340816E+04	3.225621E+02
4	2.630946E+06	1.675365E+03	4.354617E+02	0.000000E+00	6.515309E+03	1.979371E+02	3.788321E+05	1.582289E+03	2.771120E+02

Starting with the polynomial-based power distributions of VARPOW, the mesh-averaged scalar neutron and gamma flux (units are n/cm^2/s) are listed in Table 3.10 through Table 3.13. These results were obtained from the first moment (m=0) in the NHFLUX and GHFLUX files, an excerpt of which is simply impractical to show here. The higher order flux moments (m>0) are not listed explicitly to make this report concise. The mesh numbering was given earlier in Figure 3-1.

Table 3.10. Oxide Fuel, Sodium Coolant Mesh-averaged Scalar Neutron Flux

mesh	Energy Group			
	1	2	3	4
1	5.812664E+08	5.741582E+08	2.588584E+06	1.661183E+06
2	3.945154E+08	4.168122E+08	1.914363E+06	1.657795E+06
3	1.058795E+08	2.286762E+08	1.326776E+06	1.084325E+07
4	1.466897E+07	3.839476E+07	1.501933E+05	4.591099E+05
5	3.945154E+08	4.168122E+08	1.914363E+06	1.657795E+06
6	2.694558E+08	3.058514E+08	1.430036E+06	1.606048E+06
7	7.364924E+07	1.712935E+08	9.955413E+05	8.674952E+06
8	1.080364E+07	2.924229E+07	1.147343E+05	3.638306E+05
9	1.058795E+08	2.286762E+08	1.326776E+06	1.084325E+07
10	7.364924E+07	1.712935E+08	9.955413E+05	8.674952E+06
11	2.848559E+07	8.822994E+07	5.157211E+05	5.750321E+06
12	5.828091E+06	1.541742E+07	6.093327E+04	1.630679E+05
13	1.466897E+07	3.839476E+07	1.501933E+05	4.591099E+05
14	1.080364E+07	2.924229E+07	1.147343E+05	3.638306E+05
15	5.828091E+06	1.541742E+07	6.093327E+04	1.630679E+05
16	1.689447E+06	3.937657E+06	1.461265E+04	2.618469E+04

Table 3.11. Oxide Fuel, Sodium Coolant Mesh-averaged Scalar Gamma flux Groups 1-7

mesh	Gamma Group						
	1	2	3	4	5	6	7
1	3.826738E+02	5.137019E+04	3.005361E+05	3.262960E+05	9.592414E+05	2.438424E+06	5.991372E+06
2	2.750536E+02	3.882951E+04	2.349361E+05	2.335264E+05	6.658092E+05	1.683308E+06	4.119592E+06
3	2.033300E+02	4.412847E+04	3.496762E+05	1.358676E+05	1.409518E+05	2.814551E+05	5.557102E+05
4	5.670312E+00	1.509008E+03	1.377974E+04	6.397435E+03	9.280740E+03	6.724585E+04	1.627687E+05
5	2.750536E+02	3.882951E+04	2.349361E+05	2.335264E+05	6.658092E+05	1.683308E+06	4.119592E+06
6	1.983172E+02	2.941335E+04	1.845044E+05	1.689476E+05	4.668248E+05	1.173396E+06	2.859258E+06
7	1.419847E+02	3.195808E+04	2.623716E+05	1.007340E+05	1.028911E+05	2.043497E+05	3.987221E+05
8	4.283976E+00	1.154511E+03	1.060230E+04	4.854729E+03	6.895080E+03	5.066336E+04	1.224353E+05
9	2.033300E+02	4.412847E+04	3.496762E+05	1.358676E+05	1.409518E+05	2.814551E+05	5.557102E+05
10	1.419847E+02	3.195808E+04	2.623716E+05	1.007340E+05	1.028911E+05	2.043497E+05	3.987221E+05
11	5.686419E+01	1.486180E+04	1.382652E+05	4.993289E+04	4.452442E+04	8.662778E+04	1.563102E+05
12	2.754037E+00	6.889115E+02	5.857005E+03	2.533060E+03	3.105629E+03	2.545975E+04	6.127607E+04
13	5.670312E+00	1.509008E+03	1.377974E+04	6.397435E+03	9.280740E+03	6.724585E+04	1.627687E+05
14	4.283976E+00	1.154511E+03	1.060230E+04	4.854729E+03	6.895080E+03	5.066336E+04	1.224353E+05
15	2.754037E+00	6.889115E+02	5.857005E+03	2.533060E+03	3.105629E+03	2.545975E+04	6.127607E+04
16	6.311011E-01	1.437376E+02	1.147907E+03	5.284908E+02	7.017945E+02	6.759122E+03	1.652474E+04

Using the mesh-averged scalar neutron and gamma flux, as well as the associated macroscopic cross sections listed in Table 3.6 to Table 3.9, it is possible to calculate the mesh-averaged power density by hand. To check all of the numbers, an Excel file is provided to demonstrate how the power density distribution is calculated and verify the VARPOW results. The calculation involving

the higher order neutron and gamma flux moments (i.e. non mesh-averaged values) are also included in the Excel file.

Table 3.12. Oxide Fuel, Sodium Coolant Mesh-averaged Scalar Gamma flux Groups 8-14

mesh	Gamma Group						
	8	9	10	11	12	13	14
1	6.291632E+06	1.016225E+07	1.533341E+07	2.444210E+07	2.459423E+07	2.774914E+07	1.227781E+07
2	4.318136E+06	6.967433E+06	1.049506E+07	1.672147E+07	1.701039E+07	1.916732E+07	8.594090E+06
3	5.038296E+05	7.040724E+05	9.247633E+05	1.376547E+06	3.552152E+06	2.792458E+06	2.194582E+06
4	1.973216E+05	3.597785E+05	5.111698E+05	6.084595E+05	5.051795E+05	6.220016E+05	1.984796E+05
5	4.318136E+06	6.967433E+06	1.049506E+07	1.672147E+07	1.701039E+07	1.916732E+07	8.594090E+06
6	2.991261E+06	4.821442E+06	7.250045E+06	1.154362E+07	1.186203E+07	1.335803E+07	6.063891E+06
7	3.596931E+05	5.015275E+05	6.581812E+05	9.733742E+05	2.490155E+06	1.983342E+06	1.554684E+06
8	1.485157E+05	2.709728E+05	3.845069E+05	4.557727E+05	3.787756E+05	4.669179E+05	1.496189E+05
9	5.038296E+05	7.040724E+05	9.247633E+05	1.376547E+06	3.552152E+06	2.792458E+06	2.194582E+06
10	3.596931E+05	5.015275E+05	6.581812E+05	9.733742E+05	2.490155E+06	1.983342E+06	1.554684E+06
11	1.361674E+05	1.848876E+05	2.341373E+05	3.199133E+05	9.280823E+05	7.319951E+05	5.894435E+05
12	7.466704E+04	1.366245E+05	1.925249E+05	2.234161E+05	1.936615E+05	2.335663E+05	7.924175E+04
13	1.973216E+05	3.597785E+05	5.111698E+05	6.084595E+05	5.051795E+05	6.220016E+05	1.984796E+05
14	1.485157E+05	2.709728E+05	3.845069E+05	4.557727E+05	3.787756E+05	4.669179E+05	1.496189E+05
15	7.466704E+04	1.366245E+05	1.925249E+05	2.234161E+05	1.936615E+05	2.335663E+05	7.924175E+04
16	2.037973E+04	3.753625E+04	5.300355E+04	6.131576E+04	5.147582E+04	6.245213E+04	2.042081E+04

Table 3.13. Oxide Fuel, Sodium Coolant Mesh-averaged Scalar Gamma flux Groups 15-21

mesh	Gamma Group						
	15	16	17	18	19	20	21
1	4.809669E+06	4.772542E+05	1.765449E+05	2.459552E+05	1.467166E+04	2.806838E+03	1.527546E+03
2	3.479626E+06	3.492420E+05	1.255313E+05	1.686508E+05	1.005401E+04	1.927903E+03	1.056889E+03
3	3.224028E+06	8.629775E+05	1.548819E+05	1.632800E+04	1.338444E+03	2.604115E+02	9.476353E+01
4	5.902324E+04	1.014364E+04	6.528501E+03	9.717590E+03	4.448652E+02	8.321037E+01	4.930810E+01
5	3.479626E+06	3.492420E+05	1.255313E+05	1.686508E+05	1.005401E+04	1.927903E+03	1.056889E+03
6	2.524196E+06	2.564019E+05	8.960381E+04	1.160166E+05	6.931129E+03	1.333941E+03	7.375154E+02
7	2.281448E+06	6.107441E+05	1.096931E+05	1.168993E+04	9.905764E+02	1.926788E+02	7.002964E+01
8	4.548434E+04	7.705538E+03	4.928861E+03	7.230265E+03	3.288552E+02	6.159021E+01	3.670872E+01
9	3.224028E+06	8.629775E+05	1.548819E+05	1.632800E+04	1.338444E+03	2.604115E+02	9.476353E+01
10	2.281448E+06	6.107441E+05	1.096931E+05	1.168993E+04	9.905764E+02	1.926788E+02	7.002964E+01
11	9.491287E+05	2.644613E+05	4.741500E+04	4.631373E+03	4.741042E+02	9.424692E+01	3.436731E+01
12	2.925253E+04	4.811687E+03	2.709373E+03	3.870116E+03	1.768734E+02	3.309279E+01	1.962886E+01
13	5.902324E+04	1.014364E+04	6.528501E+03	9.717590E+03	4.448652E+02	8.321037E+01	4.930810E+01
14	4.548434E+04	7.705538E+03	4.928861E+03	7.230265E+03	3.288552E+02	6.159021E+01	3.670872E+01
15	2.925253E+04	4.811687E+03	2.709373E+03	3.870116E+03	1.768734E+02	3.309279E+01	1.962886E+01
16	7.149861E+03	1.244038E+03	7.173263E+02	1.086507E+03	5.055632E+01	9.413460E+00	5.462310E+00

The ‘MaterialPower.out’ file stores the mesh-averaged power densities (W/cm^3) in a six column layout, an excerpt of which is shown in Figure 3-4. The first three columns correspond to the neutron power density in the fuel, structure, and coolant regions, respectively. The last three columns correspond to the gamma power density in fuel, structure, and coolant regions, respectively. The data stored in the ‘MaterialPower.out’ file calculated by VARPOW using the GAMSOR input is shown in Table 3.14. Also included in this table is the relative difference

between the hand calculation (Excel file) and VARPOW. A quick survey of the results indicates that the relative difference in the results is less than 10^{-7}, which is primarily due to the truncation error on the inputs used for the hand calculation. It should be noted that the 'MaterialPower.out' file is created the same way regardless of the VARPOW iOutput option.

As explained earlier, the 'Output.VARPOW' file is a NHFLUX formatted binary file which the utility code PrintTables can be used to convert into readable ASCII file. As discussed, the number of vectors (stored using group index) that appear in the 'Output.VARPOW' file can be different (either 3 or 7) due to the VARPOW iOutput input. An excerpt of the PrintTables dump of the three vector file (iOutput option P) is shown in Figure 3-5 for the GAMSOR input path of VARPOW.

As seen, the 3 vector output corresponds to 3 energy groups of output. Group 1 corresponds to the neutron power density, group 2 corresponds to the gamma power density and group 3 corresponds to the fast neutron flux. The 16 rows of output for each group correspond to the number of meshes in this problem. The first moment in each row in each mesh corresponds to the mesh averaged quantity (power density or fast flux) while the rest are the higher order spatial polynomial coefficients. To enable a viewable hand calculation and one that is tractable in Excel, a lower order spatial approximation (2^{nd} order) was used in DIF3D-VARIANT leading to just 6 spatial polynomials per mesh. The number of monomials is the same as that of the polynomial terms.

Both the 'MaterialPower.out' and PrintTables dump of 'Output.VARPOW' were tabulated into Table 3.14 through Table 3.17 for the comparison against the hand calculation. Because the hand calculation is so extensive, all of the details of the hand calculation are not included here but can be found in the companion Excel document. From Table 3.14 through Table 3.17 one finds that the relative difference is on the order of 10^{-7} or smaller which is consistent with the truncation error on the input to Excel.

For the seven vector output in 'Output.VARPOW' (iOutput option T), an excerpt of the PrintTables output is shown in Figure 3-6. As seen, this output has seven groups. The first three correspond to the neutron power density in the fuel, structure, and coolant components, respectively. The next three (4-6) correspond to the gamma power density in the fuel, structure, and coolant, respectively. The last one (7) is the fast neutron flux. There are again 16 rows for each vector (group) as seen in Figure 3-5, but that detail has been truncated for brevity here. The moment (second column) of the output corresponds to the mesh-averaged value and thus is identical to the result stored in the 'MaterialPower.out' file seen in Figure 3-4. The remainder of the columns for each mesh correspond to the higher order polynomial coefficients. This output was tabulated and the Excel verification of the calculated neutron and gamma power densities for all spatial moments are provided in

Table 3.18 through Table 3.23. A quick review shows that the relative difference is on the order of 10^{-7} or smaller which is consistent with the truncation error of the input to Excel. The fast

neutron flux moments stored in the seven vector ‘Output.VARPOW’ file are the same as those in the three vector ‘Output.VARPOW’ file, and will not be checked again (compare vector 3 from Figure 3-5 to vector 7 from Figure 3-6). For all the VARPOW results, the power density is in the unit of W/cm^3.

```
# This is the VARPOW material power density (watts/cc) for all active meshes
# MatPowerDensity(6,NINTXY,NINTK) NINTXY=    16 NINTK=     1
 9.179251179E-05  9.651545792E-08  1.467943485E-07  4.784278195E-06  1.169170739E-06  2.827907474E-07
 6.460594519E-05  6.605765716E-08  1.004229540E-07  3.324749072E-06  8.065131636E-07  1.948826402E-07
 0.000000000E+00  7.819267784E-08  1.380055066E-08  0.000000000E+00  5.401087603E-07  1.393153074E-08
 6.581196271E-07  2.758932778E-09  2.801155746E-09  2.246739520E-07  2.963151275E-08  4.843903538E-09
 6.460594519E-05  6.605765716E-08  1.004229540E-07  3.324749072E-06  8.065131636E-07  1.948826402E-07
 4.594714426E-05  4.554772334E-08  6.920678928E-08  2.330077585E-06  5.614789736E-07  1.355409033E-07
 0.000000000E+00  5.535856058E-08  9.761832389E-09  0.000000000E+00  3.870351849E-07  9.970105816E-09
 4.915661745E-07  2.050454813E-09  2.080948880E-09  1.691543605E-07  2.228315532E-08  3.642039983E-09
 0.000000000E+00  7.819267784E-08  1.380055066E-08  0.000000000E+00  5.401087603E-07  1.393153074E-08
 0.000000000E+00  5.535856058E-08  9.761832389E-09  0.000000000E+00  3.870351849E-07  9.970105816E-09
 0.000000000E+00  2.315226283E-08  4.067284967E-09  0.000000000E+00  1.561653884E-07  3.953320333E-09
 2.617452325E-07  1.099257791E-09  1.115940316E-09  8.714356796E-08  1.122192537E-08  1.830355788E-09
 6.581196271E-07  2.758932778E-09  2.801155746E-09  2.246739520E-07  2.963151275E-08  4.843903538E-09
 4.915661745E-07  2.050454813E-09  2.080948880E-09  1.691543605E-07  2.228315532E-08  3.642039983E-09
 2.617452325E-07  1.099257791E-09  1.115940316E-09  8.714356796E-08  1.122192537E-08  1.830355788E-09
 7.180873179E-08  3.084481320E-10  3.136198059E-10  2.313712451E-08  3.014775876E-09  4.930261663E-10
```

Figure 3-4. Excerpt of PMATRX Based ‘MaterialPower.out’ Calculated by VARPOW

```
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      1
[NHFLUX]...XY Node; Nodal moments ->
    1  9.203582159E-05 -4.196500771E-06 -4.196500771E-06 -1.024791229E-06  0.000000000E+00 -1.024791229E-06
    2  6.477242580E-05 -1.068874443E-05 -2.878548492E-06 -3.622938183E-07  0.000000000E+00 -7.074865564E-07
    3  9.199322851E-08 -4.361194446E-08 -4.216328338E-09  7.860282589E-09  0.000000000E+00 -1.231543339E-09
    4  6.636797156E-07 -4.910277413E-07 -2.699036719E-08  1.155209430E-07  0.000000000E+00 -8.859182468E-09
    5  6.477242580E-05 -1.068874443E-05 -2.878548492E-06 -3.622938183E-07  0.000000000E+00 -7.074865564E-07
    6  4.606189877E-05 -7.305768569E-06 -7.305768569E-06 -2.286242498E-07  0.000000000E+00 -2.286242498E-07
    7  6.512039297E-08 -3.000789908E-08 -1.048758278E-08  5.250358941E-09  0.000000000E+00 -6.032273225E-10
    8  4.956975782E-07 -3.620961755E-07 -6.248893643E-08  8.375266364E-08  0.000000000E+00 -3.045699570E-09
    9  9.199322851E-08 -4.361194446E-08 -4.216328338E-09  7.860282589E-09  0.000000000E+00 -1.231543339E-09
   10  6.512039297E-08 -3.000789908E-08 -1.048758278E-08  5.250358941E-09  0.000000000E+00 -6.032273225E-10
   11  2.721954779E-08 -9.413414452E-09 -9.413414452E-09  9.312906105E-10  0.000000000E+00  9.312906105E-10
   12  2.639604306E-07 -1.852717241E-07 -6.445822402E-08  3.963629125E-08  0.000000000E+00  2.257498502E-09
   13  6.636797156E-07 -4.910277413E-07 -2.699036719E-08  1.155209430E-07  0.000000000E+00 -8.859182468E-09
   14  4.956975782E-07 -3.620961755E-07 -6.248893643E-08  8.375266364E-08  0.000000000E+00 -3.045699570E-09
   15  2.639604306E-07 -1.852717241E-07 -6.445822402E-08  3.963629125E-08  0.000000000E+00  2.257498502E-09
   16  7.243079972E-08 -4.213566079E-08 -4.213566079E-08  5.344873186E-09  0.000000000E+00  5.344873186E-09
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      2
[NHFLUX]...XY Node; Nodal moments ->
    1  6.236239681E-06 -3.062901979E-07 -3.062901979E-07 -9.045382740E-08  0.000000000E+00 -9.045382740E-08
    2  4.326144876E-06 -8.966087278E-07 -2.072419214E-07 -1.533658145E-07  0.000000000E+00 -5.899781523E-08
    3  5.540402910E-07 -3.639973560E-07 -2.445740459E-08  1.911193123E-07  0.000000000E+00 -9.858951721E-09
    4  2.591493683E-07 -2.047072264E-07 -1.012808997E-08  5.184274525E-08  0.000000000E+00 -3.573751972E-09
    5  4.326144876E-06 -8.966087278E-07 -2.072419214E-07 -1.533658145E-07  0.000000000E+00 -5.899781523E-08
    6  3.027097462E-06 -6.128138945E-07 -6.128138945E-07 -1.099753785E-07  0.000000000E+00 -1.099753785E-07
    7  3.970052907E-07 -2.525068777E-07 -6.050670273E-08  1.339904382E-07  0.000000000E+00 -5.384178423E-09
    8  1.950795558E-07 -1.523571422E-07 -2.490316934E-08  3.731459124E-08  0.000000000E+00 -1.970663662E-09
    9  5.540402910E-07 -3.639973560E-07 -2.445740459E-08  1.911193123E-07  0.000000000E+00 -9.858951721E-09
   10  3.970052907E-07 -2.525068777E-07 -6.050670273E-08  1.339904382E-07  0.000000000E+00 -5.384178423E-09
   11  1.601187087E-07 -4.907162217E-08 -4.907162217E-08  1.565371262E-08  0.000000000E+00  1.565371262E-08
   12  1.001958491E-07 -7.020927679E-08 -2.599181961E-08  1.138038471E-08  0.000000000E+00  1.933630727E-09
   13  2.591493683E-07 -2.047072264E-07 -1.012808997E-08  5.184274525E-08  0.000000000E+00 -3.573751972E-09
   14  1.950795558E-07 -1.523571422E-07 -2.490316934E-08  3.731459124E-08  0.000000000E+00 -1.970663662E-09
   15  1.001958491E-07 -7.020927679E-08 -2.599181961E-08  1.138038471E-08  0.000000000E+00  1.933630727E-09
   16  2.664492655E-08 -1.613620754E-08 -1.613620754E-08  1.954665210E-09  0.000000000E+00  1.954665210E-09
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      3
[NHFLUX]...XY Node; Nodal moments ->
    1  5.946850657E+08 -2.788853840E+07 -2.788853840E+07 -6.985667977E+06  0.000000000E+00 -6.985667977E+06
    2  4.042566862E+08 -8.414683727E+07 -1.861705362E+07 -8.605750020E+06  0.000000000E+00 -4.601904319E+06
    3  1.112239225E+08 -5.798819388E+07 -5.230005499E+06  1.234514618E+07  0.000000000E+00 -1.585116457E+06
    4  1.556628816E+07 -1.054501872E+07 -6.666018288E+05  2.038956084E+06  0.000000000E+00 -2.090117978E+05
    5  4.042566862E+08 -8.414683727E+07 -1.861705362E+07 -8.605750020E+06  0.000000000E+00 -4.601904319E+06
    6  2.766038065E+08 -5.685527407E+07 -5.685527407E+07 -5.974422242E+06  0.000000000E+00 -5.974422242E+06
    7  7.765253720E+07 -3.956119942E+07 -1.316669295E+07  8.315418658E+06  0.000000000E+00 -8.215417914E+05
    8  1.148705748E+07 -7.584212975E+06 -1.473880639E+06  1.386839898E+06  0.000000000E+00 -4.273586275E+04
    9  1.112239225E+08 -5.798819388E+07 -5.230005499E+06  1.234514618E+07  0.000000000E+00 -1.585116457E+06
   10  7.765253720E+07 -3.956119942E+07 -1.316669295E+07  8.315418658E+06  0.000000000E+00 -8.215417914E+05
   11  3.054760522E+07 -1.108706509E+07 -1.108706509E+07  1.457536938E+06  0.000000000E+00  1.457536938E+06
   12  6.188411251E+06 -3.976097199E+06 -1.473561412E+06  6.834298969E+05  0.000000000E+00  4.381291622E+04
   13  1.556628816E+07 -1.054501872E+07 -6.666018288E+05  2.038956084E+06  0.000000000E+00 -2.090117978E+05
   14  1.148705748E+07 -7.584212975E+06 -1.473880639E+06  1.386839898E+06  0.000000000E+00 -4.273586275E+04
   15  6.188411251E+06 -3.976097199E+06 -1.473561412E+06  6.834298969E+05  0.000000000E+00  4.381291622E+04
   16  1.781474098E+06 -9.898046974E+05 -9.898046974E+05  1.065396643E+05  0.000000000E+00  1.065396643E+05
```

Figure 3-5. PrintTables Excerpt for PMATRX Based ‘Output.VARPOW’ (iOption=P)

Table 3.14. Verification of the PMATRX Based Power Density Output from 'MaterialPower.out'

	mesh	neutron power density			gamma power density		
		fuel	cladding	coolant	fuel	cladding	coolant
VARPOW power density (Wcm^3)	1	9.179251E-05	9.651546E-08	1.467943E-07	4.784278E-06	1.169171E-06	2.827907E-07
	2	6.460595E-05	6.605766E-08	1.004230E-07	3.324749E-06	8.065132E-07	1.948826E-07
	3	0.000000E+00	7.819268E-08	1.380055E-08	0.000000E+00	5.401088E-07	1.393153E-08
	4	6.581196E-07	2.758933E-09	2.801156E-09	2.246740E-07	2.963151E-08	4.843904E-09
	5	6.460595E-05	6.605766E-08	1.004230E-07	3.324749E-06	8.065132E-07	1.948826E-07
	6	4.594714E-05	4.554772E-08	6.920679E-08	2.330078E-06	5.614790E-07	1.355409E-07
	7	0.000000E+00	5.535856E-08	9.761832E-09	0.000000E+00	3.870352E-07	9.970106E-09
	8	4.915662E-07	2.050455E-09	2.080949E-09	1.691544E-07	2.228316E-08	3.642040E-09
	9	0.000000E+00	7.819268E-08	1.380055E-08	0.000000E+00	5.401088E-07	1.393153E-08
	10	0.000000E+00	5.535856E-08	9.761832E-09	0.000000E+00	3.870352E-07	9.970106E-09
	11	0.000000E+00	2.315226E-08	4.067285E-09	0.000000E+00	1.561654E-07	3.953320E-09
	12	2.617452E-07	1.099258E-09	1.115940E-09	8.714357E-08	1.122193E-08	1.830356E-09
	13	6.581196E-07	2.758933E-09	2.801156E-09	2.246740E-07	2.963151E-08	4.843904E-09
	14	4.915662E-07	2.050455E-09	2.080949E-09	1.691544E-07	2.228316E-08	3.642040E-09
	15	2.617452E-07	1.099258E-09	1.115940E-09	8.714357E-08	1.122193E-08	1.830356E-09
	16	7.180873E-08	3.084481E-10	3.136198E-10	2.313712E-08	3.014776E-09	4.930262E-10
Rela. Diff.	1	-4.83E-08	6.63E-08	1.94E-07	-1.95E-08	4.34E-08	5.43E-09
	2	-4.75E-08	6.56E-08	1.93E-07	-1.94E-08	4.30E-08	5.17E-09
	3	0	9.36E-09	1.93E-07	0	-4.32E-09	2.27E-08
	4	-1.03E-07	-4.39E-08	1.34E-07	2.26E-08	-5.45E-08	-3.08E-08
	5	-4.75E-08	6.56E-08	1.93E-07	-1.94E-08	4.30E-08	5.17E-09
	6	-4.66E-08	6.51E-08	1.92E-07	-1.94E-08	4.30E-08	5.58E-09
	7	0	8.17E-09	1.91E-07	0	-4.27E-09	2.24E-08
	8	-1.01E-07	-4.48E-08	1.32E-07	2.26E-08	-5.45E-08	-3.09E-08
	9	0	9.36E-09	1.93E-07	0	-4.32E-09	2.27E-08
	10	0	8.17E-09	1.91E-07	0	-4.27E-09	2.24E-08
	11	0	3.03E-09	1.81E-07	0	-4.58E-09	2.24E-08
	12	-1.03E-07	-4.46E-08	1.33E-07	2.26E-08	-5.40E-08	-3.10E-08
	13	-1.03E-07	-4.39E-08	1.34E-07	2.26E-08	-5.45E-08	-3.08E-08
	14	-1.01E-07	-4.48E-08	1.32E-07	2.26E-08	-5.45E-08	-3.09E-08
	15	-1.03E-07	-4.46E-08	1.33E-07	2.26E-08	-5.40E-08	-3.10E-08
	16	-1.11E-07	-4.19E-08	1.37E-07	2.24E-08	-5.43E-08	-3.09E-08

Table 3.15. Verification of the PMATRX Based Neutron Power Density from 'Output.VARPOW' (iOption=P)

	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	9.20358E-05	-4.19650E-06	-4.19650E-06	-1.02479E-06	0.00E+00	-1.02479E-06
	2	6.47724E-05	-1.06887E-05	-2.87855E-06	-3.62294E-07	0.00E+00	-7.07487E-07
	3	9.19932E-08	-4.36119E-08	-4.21633E-09	7.86028E-09	0.00E+00	-1.23154E-09
	4	6.63680E-07	-4.91028E-07	-2.69904E-08	1.15521E-07	0.00E+00	-8.85918E-09
	5	6.47724E-05	-1.06887E-05	-2.87855E-06	-3.62294E-07	0.00E+00	-7.07487E-07
	6	4.60619E-05	-7.30577E-06	-7.30577E-06	-2.28624E-07	0.00E+00	-2.28624E-07
	7	6.51204E-08	-3.00079E-08	-1.04876E-08	5.25036E-09	0.00E+00	-6.03227E-10
	8	4.95698E-07	-3.62096E-07	-6.24889E-08	8.37527E-08	0.00E+00	-3.04570E-09
	9	9.19932E-08	-4.36119E-08	-4.21633E-09	7.86028E-09	0.00E+00	-1.23154E-09
	10	6.51204E-08	-3.00079E-08	-1.04876E-08	5.25036E-09	0.00E+00	-6.03227E-10
	11	2.72195E-08	-9.41341E-09	-9.41341E-09	9.31291E-10	0.00E+00	9.31291E-10
	12	2.63960E-07	-1.85272E-07	-6.44582E-08	3.96363E-08	0.00E+00	2.25750E-09
	13	6.63680E-07	-4.91028E-07	-2.69904E-08	1.15521E-07	0.00E+00	-8.85918E-09
	14	4.95698E-07	-3.62096E-07	-6.24889E-08	8.37527E-08	0.00E+00	-3.04570E-09
	15	2.63960E-07	-1.85272E-07	-6.44582E-08	3.96363E-08	0.00E+00	2.25750E-09
	16	7.24308E-08	-4.21357E-08	-4.21357E-08	5.34487E-09	0.00E+00	5.34487E-09
Rela. Diff.	1	-4.77E-08	-4.77E-08	-4.77E-08	-4.69E-08	0	-4.69E-08
	2	-4.70E-08	-5.14E-08	-4.72E-08	-6.02E-08	0	-4.59E-08
	3	3.68E-08	4.68E-08	3.95E-08	6.69E-08	0	4.32E-08
	4	-1.02E-07	-9.12E-08	-1.12E-07	-7.47E-08	0	-1.07E-07
	5	-4.70E-08	-5.14E-08	-4.72E-08	-6.02E-08	0	-4.59E-08
	6	-4.61E-08	-5.03E-08	-5.03E-08	-5.37E-08	0	-5.37E-08
	7	3.55E-08	4.61E-08	4.13E-08	6.76E-08	0	4.94E-08
	8	-9.98E-08	-8.70E-08	-1.04E-07	-6.83E-08	0	-3.90E-08
	9	3.68E-08	4.68E-08	3.95E-08	6.69E-08	0	4.32E-08
	10	3.55E-08	4.61E-08	4.13E-08	6.76E-08	0	4.94E-08
	11	2.99E-08	3.44E-08	3.44E-08	6.62E-08	0	6.62E-08
	12	-1.01E-07	-8.88E-08	-9.68E-08	-6.88E-08	0	-8.66E-08
	13	-1.02E-07	-9.12E-08	-1.12E-07	-7.47E-08	0	-1.07E-07
	14	-9.98E-08	-8.70E-08	-1.04E-07	-6.83E-08	0	-3.90E-08
	15	-1.01E-07	-8.88E-08	-9.68E-08	-6.88E-08	0	-8.66E-08
	16	-1.10E-07	-1.01E-07	-1.01E-07	-7.99E-08	0	-7.99E-08

Table 3.16. Verification of the PMATRX Based Gamma Power Density from 'Output.VARPOW' (iOption=P)

	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	6.23624E-06	-3.06290E-07	-3.06290E-07	-9.04538E-08	0.00E+00	-9.04538E-08
	2	4.32614E-06	-8.96609E-07	-2.07242E-07	-1.53366E-07	0.00E+00	-5.89978E-08
	3	5.54040E-07	-3.63997E-07	-2.44574E-08	1.91119E-07	0.00E+00	-9.85895E-09
	4	2.59149E-07	-2.04707E-07	-1.01281E-08	5.18427E-08	0.00E+00	-3.57375E-09
	5	4.32614E-06	-8.96609E-07	-2.07242E-07	-1.53366E-07	0.00E+00	-5.89978E-08
	6	3.02710E-06	-6.12814E-07	-6.12814E-07	-1.09975E-07	0.00E+00	-1.09975E-07
	7	3.97005E-07	-2.52507E-07	-6.05067E-08	1.33990E-07	0.00E+00	-5.38418E-09
	8	1.95080E-07	-1.52357E-07	-2.49032E-08	3.73146E-08	0.00E+00	-1.97066E-09
	9	5.54040E-07	-3.63997E-07	-2.44574E-08	1.91119E-07	0.00E+00	-9.85895E-09
	10	3.97005E-07	-2.52507E-07	-6.05067E-08	1.33990E-07	0.00E+00	-5.38418E-09
	11	1.60119E-07	-4.90716E-08	-4.90716E-08	1.56537E-08	0.00E+00	1.56537E-08
	12	1.00196E-07	-7.02093E-08	-2.59918E-08	1.13804E-08	0.00E+00	1.93363E-09
	13	2.59149E-07	-2.04707E-07	-1.01281E-08	5.18427E-08	0.00E+00	-3.57375E-09
	14	1.95080E-07	-1.52357E-07	-2.49032E-08	3.73146E-08	0.00E+00	-1.97066E-09
	15	1.00196E-07	-7.02093E-08	-2.59918E-08	1.13804E-08	0.00E+00	1.93363E-09
	16	2.66449E-08	-1.61362E-08	-1.61362E-08	1.95467E-09	0.00E+00	1.95467E-09
Rela. Diff.	1	-6.48E-09	-6.15E-09	-6.15E-09	-5.44E-09	0	-5.44E-09
	2	-6.67E-09	-5.51E-09	-6.32E-09	-1.14E-10	0	-5.25E-09
	3	-3.57E-09	-3.56E-09	-3.62E-09	-3.22E-09	0	-3.66E-09
	4	1.27E-08	1.25E-08	1.29E-08	1.25E-08	0	1.26E-08
	5	-6.67E-09	-5.51E-09	-6.32E-09	-1.14E-10	0	-5.25E-09
	6	-6.73E-09	-5.60E-09	-5.60E-09	-5.58E-10	0	-5.58E-10
	7	-3.56E-09	-3.71E-09	-3.56E-09	-3.48E-09	0	-3.54E-09
	8	1.28E-08	1.31E-08	1.27E-08	1.28E-08	0	1.31E-08
	9	-3.57E-09	-3.56E-09	-3.62E-09	-3.22E-09	0	-3.66E-09
	10	-3.56E-09	-3.71E-09	-3.56E-09	-3.48E-09	0	-3.54E-09
	11	-3.71E-09	-3.64E-09	-3.64E-09	-3.29E-09	0	-3.29E-09
	12	1.32E-08	1.33E-08	1.27E-08	1.65E-08	0	1.19E-08
	13	1.27E-08	1.25E-08	1.29E-08	1.25E-08	0	1.26E-08
	14	1.28E-08	1.31E-08	1.27E-08	1.28E-08	0	1.31E-08
	15	1.32E-08	1.33E-08	1.27E-08	1.65E-08	0	1.19E-08
	16	1.28E-08	1.31E-08	1.31E-08	1.38E-08	0	1.38E-08

Table 3.17. Verification of the Fast Neutron Flux from 'Output.VARPOW' (iOption=P)

	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW Fast neutron flux	1	5.94685E+08	-2.78885E+07	-2.78885E+07	-6.98567E+06	0.00E+00	-6.98567E+06
	2	4.04257E+08	-8.41468E+07	-1.86171E+07	-8.60575E+06	0.00E+00	-4.60190E+06
	3	1.11224E+08	-5.79882E+07	-5.23001E+06	1.23451E+07	0.00E+00	-1.58512E+06
	4	1.55663E+07	-1.05450E+07	-6.66602E+05	2.03896E+06	0.00E+00	-2.09012E+05
	5	4.04257E+08	-8.41468E+07	-1.86171E+07	-8.60575E+06	0.00E+00	-4.60190E+06
	6	2.76604E+08	-5.68553E+07	-5.68553E+07	-5.97442E+06	0.00E+00	-5.97442E+06
	7	7.76525E+07	-3.95612E+07	-1.31667E+07	8.31542E+06	0.00E+00	-8.21542E+05
	8	1.14871E+07	-7.58421E+06	-1.47388E+06	1.38684E+06	0.00E+00	-4.27359E+04
	9	1.11224E+08	-5.79882E+07	-5.23001E+06	1.23451E+07	0.00E+00	-1.58512E+06
	10	7.76525E+07	-3.95612E+07	-1.31667E+07	8.31542E+06	0.00E+00	-8.21542E+05
	11	3.05476E+07	-1.10871E+07	-1.10871E+07	1.45754E+06	0.00E+00	1.45754E+06
	12	6.18841E+06	-3.97610E+06	-1.47356E+06	6.83430E+05	0.00E+00	4.38129E+04
	13	1.55663E+07	-1.05450E+07	-6.66602E+05	2.03896E+06	0.00E+00	-2.09012E+05
	14	1.14871E+07	-7.58421E+06	-1.47388E+06	1.38684E+06	0.00E+00	-4.27359E+04
	15	6.18841E+06	-3.97610E+06	-1.47356E+06	6.83430E+05	0.00E+00	4.38129E+04
	16	1.78147E+06	-9.89805E+05	-9.89805E+05	1.06540E+05	0.00E+00	1.06540E+05
Rela. Diff.	1	-8.04E-10	-5.80E-10	-5.80E-10	-7.74E-10	0	-7.74E-10
	2	-9.79E-10	-5.46E-10	-5.70E-10	1.88E-10	0	-7.79E-10
	3	-1.96E-09	-9.40E-10	-1.63E-09	7.21E-10	0	-1.28E-09
	4	-2.07E-09	-3.10E-09	-1.87E-09	-3.15E-09	0	-2.03E-09
	5	-9.79E-10	-5.46E-10	-5.70E-10	1.88E-10	0	-7.79E-10
	6	-7.62E-10	-6.28E-10	-6.28E-10	2.82E-10	0	2.82E-10
	7	-2.06E-09	-8.55E-10	-9.87E-10	3.81E-10	0	-7.45E-10
	8	-2.55E-09	-2.67E-09	-2.22E-09	-3.32E-09	0	-5.61E-09
	9	-1.96E-09	-9.40E-10	-1.63E-09	7.21E-10	0	-1.28E-09
	10	-2.06E-09	-8.55E-10	-9.87E-10	3.81E-10	0	-7.45E-10
	11	-2.67E-09	-2.21E-09	-2.21E-09	3.78E-10	0	3.78E-10
	12	-2.36E-09	-2.65E-09	-2.28E-09	-3.74E-09	0	-2.87E-09
	13	-2.07E-09	-3.10E-09	-1.87E-09	-3.15E-09	0	-2.03E-09
	14	-2.55E-09	-2.67E-09	-2.22E-09	-3.32E-09	0	-5.61E-09
	15	-2.36E-09	-2.65E-09	-2.28E-09	-3.74E-09	0	-2.87E-09
	16	-2.00E-09	-2.25E-09	-2.25E-09	-3.52E-09	0	-3.52E-09

```
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      1
[NHFLUX]...XY Node; Nodal moments ->
    1  9.179251179E-05 -4.185141455E-06 -4.185141455E-06 -1.021953869E-06  0.000000000E+00 -1.021953869E-06
    2  6.460594519E-05 -1.065539267E-05 -2.870925580E-06 -3.591824608E-07  0.000000000E+00 -7.056008808E-07
    3  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      2
[NHFLUX]...XY Node; Nodal moments ->
    1  9.651545792E-08 -4.505094500E-09 -4.505094500E-09 -1.125149422E-09  0.000000000E+00 -1.125149422E-09
    2  6.605765716E-08 -1.321130657E-08 -3.023926564E-09 -1.227074382E-09  0.000000000E+00 -7.480458673E-10
    3  7.819267784E-08 -3.703373715E-08 -3.582928098E-09  6.661401848E-09  0.000000000E+00 -1.046137235E-09
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      3
[NHFLUX]...XY Node; Nodal moments ->
    1  1.467943485E-07 -6.854221572E-09 -6.854221572E-09 -1.712211057E-09  0.000000000E+00 -1.712211057E-09
    2  1.004229540E-07 -2.014045510E-08 -4.598985327E-09 -1.884283089E-09  0.000000000E+00 -1.137629751E-09
    3  1.380055066E-08 -6.578207310E-09 -6.334002405E-10  1.198880741E-09  0.000000000E+00 -1.854061042E-10
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      4
[NHFLUX]...XY Node; Nodal moments ->
    1  4.784278195E-06 -2.334307920E-07 -2.334307920E-07 -6.769228770E-08  0.000000000E+00 -6.769228770E-08
    2  3.324749072E-06 -6.725643059E-07 -1.578411462E-07 -1.026526033E-07  0.000000000E+00 -4.400081483E-08
    3  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      5
[NHFLUX]...XY Node; Nodal moments ->
    1  1.169170739E-06 -5.862991470E-08 -5.862991470E-08 -1.828770157E-08  0.000000000E+00 -1.828770157E-08
    2  8.065131636E-07 -1.800419247E-07 -3.975282340E-08 -4.051503270E-08  0.000000000E+00 -1.204798450E-08
    3  5.401087603E-07 -3.542040633E-07 -2.384410231E-08  1.854404062E-07  0.000000000E+00 -9.596175744E-09
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      6
[NHFLUX]...XY Node; Nodal moments ->
    1  2.827907474E-07 -1.422949120E-08 -1.422949120E-08 -4.473838123E-09  0.000000000E+00 -4.473838123E-09
    2  1.948826402E-07 -4.400249711E-08 -9.647951773E-09 -1.019817854E-08  0.000000000E+00 -2.949015899E-09
    3  1.393153074E-08 -9.793292698E-09 -6.133022819E-10  5.678906189E-09  0.000000000E+00 -2.627759765E-10
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      7
[NHFLUX]...XY Node; Nodal moments ->
    1  5.946850657E+08 -2.788853840E+07 -2.788853840E+07 -6.985667977E+06  0.000000000E+00 -6.985667977E+06
    2  4.042566862E+08 -8.414683727E+07 -1.861705362E+07 -8.605750020E+06  0.000000000E+00 -4.601904319E+06
    3  1.112239225E+08 -5.798819388E+07 -5.230005499E+06  1.234514618E+07  0.000000000E+00 -1.585116457E+06
.....
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Figure 3-6. PrintTables Excerpt for PMATRX Based ‘Output.VARPOW’ (iOption=T)

Table 3.18. Verification of the PMATRX Based Fuel Neutron Power Density from 'Output.VARPOW' (iOption=T)

	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	9.17925E-05	-4.18514E-06	-4.18514E-06	-1.02195E-06	0.00E+00	-1.02195E-06
	2	6.46059E-05	-1.06554E-05	-2.87093E-06	-3.59182E-07	0.00E+00	-7.05601E-07
	3	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	4	6.58120E-07	-4.87119E-07	-2.67591E-08	1.14706E-07	0.00E+00	-8.78545E-09
	5	6.46059E-05	-1.06554E-05	-2.87093E-06	-3.59182E-07	0.00E+00	-7.05601E-07
	6	4.59471E-05	-7.28318E-06	-7.28318E-06	-2.26467E-07	0.00E+00	-2.26467E-07
	7	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	8	4.91566E-07	-3.59247E-07	-6.19645E-08	8.31804E-08	0.00E+00	-3.02555E-09
	9	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	10	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	11	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	12	2.61745E-07	-1.83790E-07	-6.39240E-08	3.93574E-08	0.00E+00	2.24077E-09
	13	6.58120E-07	-4.87119E-07	-2.67591E-08	1.14706E-07	0.00E+00	-8.78545E-09
	14	4.91566E-07	-3.59247E-07	-6.19645E-08	8.31804E-08	0.00E+00	-3.02555E-09
	15	2.61745E-07	-1.83790E-07	-6.39240E-08	3.93574E-08	0.00E+00	2.24077E-09
	16	7.18087E-08	-4.17816E-08	-4.17816E-08	5.30380E-09	0.00E+00	5.30380E-09
Rela. Diff.	1	-4.83E-08	-4.83E-08	-4.83E-08	-4.79E-08	0	-4.79E-08
	2	-4.75E-08	-5.22E-08	-4.76E-08	-6.21E-08	0	-4.64E-08
	3	0	0	0	0	0	0
	4	-1.03E-07	-9.22E-08	-1.14E-07	-7.59E-08	0	-1.08E-07
	5	-4.75E-08	-5.22E-08	-4.76E-08	-6.21E-08	0	-4.64E-08
	6	-4.66E-08	-5.08E-08	-5.08E-08	-5.57E-08	0	-5.57E-08
	7	0	0	0	0	0	0
	8	-1.01E-07	-8.81E-08	-1.05E-07	-6.89E-08	0	-3.96E-08
	9	0	0	0	0	0	0
	10	0	0	0	0	0	0
	11	0	0	0	0	0	0
	12	-1.03E-07	-8.99E-08	-9.80E-08	-6.94E-08	0	-8.75E-08
	13	-1.03E-07	-9.22E-08	-1.14E-07	-7.59E-08	0	-1.08E-07
	14	-1.01E-07	-8.81E-08	-1.05E-07	-6.89E-08	0	-3.96E-08
	15	-1.03E-07	-8.99E-08	-9.80E-08	-6.94E-08	0	-8.75E-08
	16	-1.11E-07	-1.02E-07	-1.02E-07	-8.09E-08	0	-8.09E-08

Table 3.19. Verification of the PMATRX Based Structure Neutron Power Density from 'Output.VARPOW' (iOption=T)

	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	9.65155E-08	-4.50509E-09	-4.50509E-09	-1.12515E-09	0.00E+00	-1.12515E-09
	2	6.60577E-08	-1.32113E-08	-3.02393E-09	-1.22707E-09	0.00E+00	-7.48046E-10
	3	7.81927E-08	-3.70337E-08	-3.58293E-09	6.66140E-09	0.00E+00	-1.04614E-09
	4	2.75893E-09	-1.94189E-09	-1.14627E-10	4.05539E-10	0.00E+00	-3.65739E-11
	5	6.60577E-08	-1.32113E-08	-3.02393E-09	-1.22707E-09	0.00E+00	-7.48046E-10
	6	4.55477E-08	-8.95010E-09	-8.95010E-09	-8.50767E-10	0.00E+00	-8.50767E-10
	7	5.53586E-08	-2.54839E-08	-8.91091E-09	4.44901E-09	0.00E+00	-5.12078E-10
	8	2.05045E-09	-1.41593E-09	-2.60204E-10	2.85208E-10	0.00E+00	-1.00759E-11
	9	7.81927E-08	-3.70337E-08	-3.58293E-09	6.66140E-09	0.00E+00	-1.04614E-09
	10	5.53586E-08	-2.54839E-08	-8.91091E-09	4.44901E-09	0.00E+00	-5.12078E-10
	11	2.31523E-08	-8.00340E-09	-8.00340E-09	7.89239E-10	0.00E+00	7.89239E-10
	12	1.09926E-09	-7.35990E-10	-2.65226E-10	1.38949E-10	0.00E+00	8.31619E-12
	13	2.75893E-09	-1.94189E-09	-1.14627E-10	4.05539E-10	0.00E+00	-3.65739E-11
	14	2.05045E-09	-1.41593E-09	-2.60204E-10	2.85208E-10	0.00E+00	-1.00759E-11
	15	1.09926E-09	-7.35990E-10	-2.65226E-10	1.38949E-10	0.00E+00	8.31619E-12
	16	3.08448E-10	-1.75714E-10	-1.75714E-10	2.04261E-11	0.00E+00	2.04261E-11
Rela. Diff.	1	6.63E-08	6.69E-08	6.69E-08	6.71E-08	0	6.71E-08
	2	6.56E-08	6.94E-08	6.62E-08	7.96E-08	0	6.62E-08
	3	9.36E-09	1.79E-08	1.15E-08	3.54E-08	0	1.45E-08
	4	-4.39E-08	-4.72E-08	-4.18E-08	-5.28E-08	0	-4.27E-08
	5	6.56E-08	6.94E-08	6.62E-08	7.96E-08	0	6.62E-08
	6	6.51E-08	6.92E-08	6.92E-08	7.96E-08	0	7.96E-08
	7	8.17E-09	1.73E-08	1.28E-08	3.59E-08	0	2.01E-08
	8	-4.48E-08	-4.77E-08	-4.40E-08	-5.51E-08	0	-6.48E-08
	9	9.36E-09	1.79E-08	1.15E-08	3.54E-08	0	1.45E-08
	10	8.17E-09	1.73E-08	1.28E-08	3.59E-08	0	2.01E-08
	11	3.03E-09	7.23E-09	7.23E-09	3.47E-08	0	3.47E-08
	12	-4.46E-08	-4.74E-08	-4.50E-08	-5.45E-08	0	-4.92E-08
	13	-4.39E-08	-4.72E-08	-4.18E-08	-5.28E-08	0	-4.27E-08
	14	-4.48E-08	-1.00E+00	-1.00E+00	-1.00E+00	0	-1.00E+00
	15	-4.46E-08	-4.74E-08	-4.50E-08	-5.45E-08	0	-4.92E-08
	16	-4.19E-08	-4.41E-08	-4.41E-08	-5.02E-08	0	-5.02E-08

Table 3.20. Verification of the PMATRX Based Coolant Neutron Power Density from 'Output.VARPOW' (iOption=T)

Data	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	1.46794E-07	-6.85422E-09	-6.85422E-09	-1.71221E-09	0.00E+00	-1.71221E-09
	2	1.00423E-07	-2.01405E-08	-4.59899E-09	-1.88428E-09	0.00E+00	-1.13763E-09
	3	1.38006E-08	-6.57821E-09	-6.33400E-10	1.19888E-09	0.00E+00	-1.85406E-10
	4	2.80116E-09	-1.96703E-09	-1.16596E-10	4.08937E-10	0.00E+00	-3.71609E-11
	5	1.00423E-07	-2.01405E-08	-4.59899E-09	-1.88428E-09	0.00E+00	-1.13763E-09
	6	6.92068E-08	-1.36418E-08	-1.36418E-08	-1.30659E-09	0.00E+00	-1.30659E-09
	7	9.76183E-09	-4.52399E-09	-1.57667E-09	8.01352E-10	0.00E+00	-9.11495E-11
	8	2.08095E-09	-1.43312E-09	-2.64248E-10	2.87076E-10	0.00E+00	-1.00753E-11
	9	1.38006E-08	-6.57821E-09	-6.33400E-10	1.19888E-09	0.00E+00	-1.85406E-10
	10	9.76183E-09	-4.52399E-09	-1.57667E-09	8.01352E-10	0.00E+00	-9.11495E-11
	11	4.06728E-09	-1.41001E-09	-1.41001E-09	1.42052E-10	0.00E+00	1.42052E-10
	12	1.11594E-09	-7.45310E-10	-2.69038E-10	1.39952E-10	0.00E+00	8.40832E-12
	13	2.80116E-09	-1.96703E-09	-1.16596E-10	4.08937E-10	0.00E+00	-3.71609E-11
	14	2.08095E-09	-1.43312E-09	-2.64248E-10	2.87076E-10	0.00E+00	-1.00753E-11
	15	1.11594E-09	-7.45310E-10	-2.69038E-10	1.39952E-10	0.00E+00	8.40832E-12
	16	3.13620E-10	-1.78388E-10	-1.78388E-10	2.06426E-11	0.00E+00	2.06426E-11
Rela. Diff.	1	1.94E-07	1.96E-07	1.96E-07	1.96E-07	0	1.96E-07
	2	1.93E-07	2.01E-07	1.95E-07	2.19E-07	0	1.94E-07
	3	1.93E-07	2.09E-07	1.97E-07	2.42E-07	0	2.04E-07
	4	1.34E-07	1.28E-07	1.38E-07	1.16E-07	0	1.36E-07
	5	1.93E-07	2.01E-07	1.95E-07	2.19E-07	0	1.94E-07
	6	1.92E-07	2.00E-07	2.00E-07	2.20E-07	0	2.20E-07
	7	1.91E-07	2.08E-07	1.99E-07	2.43E-07	0	2.14E-07
	8	1.32E-07	1.26E-07	1.34E-07	1.12E-07	0	9.29E-08
	9	1.93E-07	2.09E-07	1.97E-07	2.42E-07	0	2.04E-07
	10	1.91E-07	2.08E-07	1.99E-07	2.43E-07	0	2.14E-07
	11	1.81E-07	1.89E-07	1.89E-07	2.41E-07	0	2.41E-07
	12	1.33E-07	1.27E-07	1.31E-07	1.13E-07	0	1.23E-07
	13	1.34E-07	1.28E-07	1.38E-07	1.16E-07	0	1.36E-07
	14	1.32E-07	1.26E-07	1.34E-07	1.12E-07	0	9.29E-08
	15	1.33E-07	1.27E-07	1.31E-07	1.13E-07	0	1.23E-07
	16	1.37E-07	1.34E-07	1.34E-07	1.22E-07	0	1.22E-07

Table 3.21. Verification of the PMATRX Based Fuel Gamma Power Density from 'Output.VARPOW' (iOption=T)

	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	4.78428E-06	-2.33431E-07	-2.33431E-07	-6.76923E-08	0.00E+00	-6.76923E-08
	2	3.32475E-06	-6.72564E-07	-1.57841E-07	-1.02653E-07	0.00E+00	-4.40008E-08
	3	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	4	2.24674E-07	-1.77438E-07	-8.78595E-09	4.49602E-08	0.00E+00	-3.09875E-09
	5	3.32475E-06	-6.72564E-07	-1.57841E-07	-1.02653E-07	0.00E+00	-4.40008E-08
	6	2.33008E-06	-4.59557E-07	-4.59557E-07	-7.41920E-08	0.00E+00	-7.41920E-08
	7	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	8	1.69154E-07	-1.32136E-07	-2.15934E-08	3.24820E-08	0.00E+00	-1.71222E-09
	9	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	10	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	11	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00E+00	0.00000E+00
	12	8.71436E-08	-6.13713E-08	-2.25519E-08	1.04953E-08	0.00E+00	1.65283E-09
	13	2.24674E-07	-1.77438E-07	-8.78595E-09	4.49602E-08	0.00E+00	-3.09875E-09
	14	1.69154E-07	-1.32136E-07	-2.15934E-08	3.24820E-08	0.00E+00	-1.71222E-09
	15	8.71436E-08	-6.13713E-08	-2.25519E-08	1.04953E-08	0.00E+00	1.65283E-09
	16	2.31371E-08	-1.40138E-08	-1.40138E-08	1.71918E-09	0.00E+00	1.71918E-09
Rela. Diff.	1	-1.95E-08	-1.92E-08	-1.92E-08	-1.92E-08	0	-1.92E-08
	2	-1.94E-08	-1.92E-08	-1.93E-08	-1.81E-08	0	-1.91E-08
	3	0	0	0	0	0	0
	4	2.26E-08	2.28E-08	2.26E-08	2.22E-08	0	2.24E-08
	5	-1.94E-08	-1.92E-08	-1.93E-08	-1.81E-08	0	-1.91E-08
	6	-1.94E-08	-1.92E-08	-1.92E-08	-1.82E-08	0	-1.82E-08
	7	0	0	0	0	0	0
	8	2.26E-08	2.27E-08	2.26E-08	2.24E-08	0	2.25E-08
	9	0	0	0	0	0	0
	10	0	0	0	0	0	0
	11	0	0	0	0	0	0
	12	0	0	0	0	0	0
	13	2.26E-08	2.28E-08	2.26E-08	2.22E-08	0	2.24E-08
	14	2.26E-08	2.27E-08	2.26E-08	2.24E-08	0	2.25E-08
	15	2.26E-08	2.26E-08	2.26E-08	2.27E-08	0	2.26E-08
	16	2.24E-08	2.25E-08	2.25E-08	2.28E-08	0	2.28E-08

Table 3.22. Verification of the PMATRX Based Structure Gamma Power Density from 'Output.VARPOW' (iOption=T)

Data	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	1.16917E-06	-5.86299E-08	-5.86299E-08	-1.82877E-08	0.00E+00	-1.82877E-08
	2	8.06513E-07	-1.80042E-07	-3.97528E-08	-4.05150E-08	0.00E+00	-1.20480E-08
	3	5.40109E-07	-3.54204E-07	-2.38441E-08	1.85440E-07	0.00E+00	-9.59618E-09
	4	2.96315E-08	-2.34518E-08	-1.15351E-09	5.93657E-09	0.00E+00	-4.08515E-10
	5	8.06513E-07	-1.80042E-07	-3.97528E-08	-4.05150E-08	0.00E+00	-1.20480E-08
	6	5.61479E-07	-1.23155E-07	-1.23155E-07	-2.85918E-08	0.00E+00	-2.85918E-08
	7	3.87035E-07	-2.45730E-07	-5.89886E-08	1.30008E-07	0.00E+00	-5.24284E-09
	8	2.22832E-08	-1.73915E-08	-2.84447E-09	4.17111E-09	0.00E+00	-2.22246E-10
	9	5.40109E-07	-3.54204E-07	-2.38441E-08	1.85440E-07	0.00E+00	-9.59618E-09
	10	3.87035E-07	-2.45730E-07	-5.89886E-08	1.30008E-07	0.00E+00	-5.24284E-09
	11	1.56165E-07	-4.79096E-08	-4.79096E-08	1.51801E-08	0.00E+00	1.51801E-08
	12	1.12219E-08	-7.60871E-09	-2.95676E-09	7.76968E-10	0.00E+00	2.40875E-10
	13	2.96315E-08	-2.34518E-08	-1.15351E-09	5.93657E-09	0.00E+00	-4.08515E-10
	14	2.22832E-08	-1.73915E-08	-2.84447E-09	4.17111E-09	0.00E+00	-2.22246E-10
	15	1.12219E-08	-7.60871E-09	-2.95676E-09	7.76968E-10	0.00E+00	2.40875E-10
	16	3.01478E-09	-1.82442E-09	-1.82442E-09	2.03235E-10	0.00E+00	2.03235E-10
Rela. Diff.	1	4.34E-08	4.30E-08	4.30E-08	4.31E-08	0	4.31E-08
	2	4.30E-08	4.34E-08	4.31E-08	4.30E-08	0	4.28E-08
	3	-4.32E-09	-4.27E-09	-4.36E-09	-4.48E-09	0	-4.32E-09
	4	-5.45E-08	-5.45E-08	-5.45E-08	-5.44E-08	0	-5.43E-08
	5	4.30E-08	4.34E-08	4.31E-08	4.30E-08	0	4.28E-08
	6	4.30E-08	4.28E-08	4.28E-08	4.32E-08	0	4.32E-08
	7	-4.27E-09	-4.38E-09	-4.25E-09	-4.00E-09	0	-4.18E-09
	8	-5.45E-08	-5.44E-08	-5.44E-08	-5.44E-08	0	-5.42E-08
	9	-4.32E-09	-4.27E-09	-4.36E-09	-4.48E-09	0	-4.32E-09
	10	-4.27E-09	-4.38E-09	-4.25E-09	-4.00E-09	0	-4.18E-09
	11	-4.58E-09	-4.19E-09	-4.19E-09	-4.44E-09	0	-4.44E-09
	12	-5.40E-08	-5.43E-08	-5.43E-08	-5.44E-08	0	-5.44E-08
	13	-5.45E-08	-5.45E-08	-5.45E-08	-5.44E-08	0	-5.43E-08
	14	-5.45E-08	-5.44E-08	-5.44E-08	-5.44E-08	0	-5.42E-08
	15	-5.40E-08	-5.43E-08	-5.43E-08	-5.44E-08	0	-5.44E-08
	16	-5.43E-08	-5.43E-08	-5.43E-08	-5.42E-08	0	-5.42E-08

Table 3.23. Verification of the PMATRX Based Coolant Gamma Power Density from 'Output.VARPOW' (iOption=T)

	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	2.82791E-07	-1.42295E-08	-1.42295E-08	-4.47384E-09	0.00E+00	-4.47384E-09
	2	1.94883E-07	-4.40025E-08	-9.64795E-09	-1.01982E-08	0.00E+00	-2.94902E-09
	3	1.39315E-08	-9.79329E-09	-6.13302E-10	5.67891E-09	0.00E+00	-2.62776E-10
	4	4.84390E-09	-3.81771E-09	-1.88631E-10	9.45943E-10	0.00E+00	-6.64884E-11
	5	1.94883E-07	-4.40025E-08	-9.64795E-09	-1.01982E-08	0.00E+00	-2.94902E-09
	6	1.35541E-07	-3.01020E-08	-3.01020E-08	-7.19163E-09	0.00E+00	-7.19163E-09
	7	9.97011E-09	-6.77687E-09	-1.51815E-09	3.98242E-09	0.00E+00	-1.41333E-10
	8	3.64204E-09	-2.82953E-09	-4.65275E-10	6.61500E-10	0.00E+00	-3.61974E-11
	9	1.39315E-08	-9.79329E-09	-6.13302E-10	5.67891E-09	0.00E+00	-2.62776E-10
	10	9.97011E-09	-6.77687E-09	-1.51815E-09	3.98242E-09	0.00E+00	-1.41333E-10
	11	3.95332E-09	-1.16202E-09	-1.16202E-09	4.73564E-10	0.00E+00	4.73564E-10
	12	1.83036E-09	-1.22926E-09	-4.83198E-10	1.08140E-10	0.00E+00	3.99279E-11
	13	4.84390E-09	-3.81771E-09	-1.88631E-10	9.45943E-10	0.00E+00	-6.64884E-11
	14	3.64204E-09	-2.82953E-09	-4.65275E-10	6.61500E-10	0.00E+00	-3.61974E-11
	15	1.83036E-09	-1.22926E-09	-4.83198E-10	1.08140E-10	0.00E+00	3.99279E-11
	16	4.93026E-10	-2.98032E-10	-2.98032E-10	3.22555E-11	0.00E+00	3.22555E-11
Rela. Diff.	1	5.43E-09	5.08E-09	5.08E-09	5.45E-09	0	5.45E-09
	2	5.17E-09	5.43E-09	5.42E-09	5.56E-09	0	5.33E-09
	3	2.27E-08	2.23E-08	2.22E-08	2.23E-08	0	2.24E-08
	4	-3.08E-08	-3.09E-08	-3.08E-08	-3.10E-08	0	-3.09E-08
	5	5.17E-09	5.43E-09	5.42E-09	5.56E-09	0	5.33E-09
	6	5.58E-09	5.38E-09	5.38E-09	5.47E-09	0	5.47E-09
	7	2.24E-08	2.22E-08	2.26E-08	2.23E-08	0	2.24E-08
	8	-3.09E-08	-3.09E-08	-3.08E-08	-3.10E-08	0	-3.09E-08
	9	2.27E-08	2.23E-08	2.22E-08	2.23E-08	0	2.24E-08
	10	2.24E-08	2.22E-08	2.26E-08	2.23E-08	0	2.24E-08
	11	2.24E-08	2.26E-08	2.26E-08	2.24E-08	0	2.24E-08
	12	-3.10E-08	-3.11E-08	-3.08E-08	-3.06E-08	0	-3.08E-08
	13	-3.08E-08	-3.09E-08	-3.08E-08	-3.10E-08	0	-3.09E-08
	14	-3.09E-08	-3.09E-08	-3.08E-08	-3.10E-08	0	-3.09E-08
	15	-3.10E-08	-3.11E-08	-3.08E-08	-3.06E-08	0	-3.08E-08
	16	-3.09E-08	-3.09E-08	-3.09E-08	-3.09E-08	0	-3.09E-08

For the VARPOW calculation using the ISOTXS input, there is no gamma power and the 'MaterialPower.out' file still has the six column layout as seen previously but the last three columns are all zeros as seen in Figure 3-7. The verification of the output in 'MaterialPower.out' is shown in Table 3.24 where the details of the hand calculation are included in the companion Excel document. From the results, one can see that the relative difference is 10^{-8} or less which is consistent with the truncation error on the input to the Excel document.

The layout of the 'Output.VARPOW' file when using ISOTXS or PMATRX based input is the same. Because the ISOTXS input path does not have gamma power, the related gamma power densities vectors are always zero in the 'Output.VARPOW' similar to that seen in the 'MaterialPower.out' file. An excerpt of the PrintTables output of the three vector 'Output.VARPOW' file based on the ISOTXS input is shown in Figure 3-8. The third vector (group) corresponds to the fast flux and a comparison of the output in Figure 3-8 matches the third vector output in Figure 3-5 and the seventh vector output in Figure 3-6 and no further verification is needed beyond that shown in Table 3.17. The verification of the three-point 'Output.VARPOW' file (iOutput=P) generated by VARPOW using the ISOTXS input is shown in Table 3.25. The hand calculation details are included in the companion Excel document and as can be seen, the difference between the results is 10^{-7} or lower which is consistent with the truncation error of the input into Excel.

All of the hand calculation results shown thusfar are done using VARPOW iOutput option P or T. In these cases, the un-normalized polynomial-based power distribution is provided in the 'Output.VARPOW' file. As explained earlier, the thermal-hydraulic code DASSH is built to use the normalized monomial-based data being stored in 'Output.VARPOW' file while EvaluateFlux is built to use the polynomial based output. For the normalized monomial basis data, the magnitude of the mesh power densities are obtained from the 'MaterialPower.out' file. It is a trivial effort to compare the 'MaterialPower.out' file and find it is identical between the monomial or polynomial basis output of VARPOW and thus it is not verified again here. The monomial basis stored in 'Output.VARPOW' file using iOutput options M and S still needs to be verified, but it should be clear that this is a minor modification of the existing polynomial output.

As shown earlier in equations 2-10 and 2-11, the polynomial basis can be converted to the monomial basis given the matrix $\hat{F}$. As discussed, this matrix is provided by VARPOW in the 'VariantMonoExponents.out' file. As part of the verification, the means to calculate the $\hat{F}$ is displayed here along with the verification against the one provided in the 'VariantMonoExponents.out' file for this test problem. Given a vector of polynomial coefficients $\bar{\varphi}_p$, the conversion to a monomial basis $\bar{\varphi}_m$ is defined as:

$$\bar{\varphi}_m = \hat{F} \cdot \bar{\varphi}_p \qquad 3\text{-}1$$

This coefficient matrix can be obtained from the volume integration matrix $\widehat{M}$ for the monomial basis as:

$$\hat{F}\hat{F}^T = \hat{M}^{-1} \quad 3\text{-}2$$

The terms in the matrix $\hat{M}_{i,j}$ are obtained from the volume integral of a monomial basis $\bar{m}(\vec{r})$.

$$\hat{M}_{i,j} = \int \bar{m}_i(\vec{r}) \cdot \bar{m}_j(\vec{r}) dV \quad 3\text{-}3$$

For Cartesian 2D geometries, the monomial integrals in DIF3D-VARIANT are defined as

$$\hat{M}_{i,j} = \int_{-0.5}^{0.5} \int_{-0.5}^{0.5} \bar{m}_i(x,y) \cdot \bar{m}_j(x,y) dx\, dy \quad 3\text{-}4$$

These of course have analytic solutions of

$$\int_{-0.5}^{0.5} x^m dx = \frac{2}{(m+1)2^{m+1}} \delta_{m \in odd} \quad 3\text{-}5$$

Figure 3-9 shows how to calculate the polynomial to monomial coefficient matrix using the preceding equations. Figure 3-10 shows an excerpt of the 'VariantMonoExponents.out' file and it is a easy to see that the monomial basis ("Mono" in Figure 3-9) is consistent with that reported in Figure 3-10. Further it is easy to see that the $\hat{F}$ matrix in Figure 3-9 is identical to that reported in Figure 3-10. It is important to point out that the "cholesky" matrix factorization is used in Figure 3-9. The output of this function is arbitrary in that it could have provided the $\hat{F}$ matrix instead of its transpose and is an implementation specific aspect. The means by which the monomial integrals can be computed from the $\hat{F}$ matrix are also shown in Figure 3-9 for completeness. It is noted that the algorithm in DIF3D-VARIANT to obtain the $\hat{F}$ matrix is Gramm-Schmidt which is computationally more efficient than that shown in Figure 3-9 but they are equivalent.

From equations 2-10 and 2-11, the conversion of the polynomial power distribution to the desired monomial one is rather straightforward given the $\hat{F}$ matrix. Consequently, the polynomial-based power distribution output of VARPOW which was verified earlier can simply be combined with the coefficient matrix to obtain the monomial distribution thus avoiding extra verfication work in Excel. Figure 3-11 shows an PrintTables generated excerpt of the 'Output.VARPOW' file for iOutput option M. One can compare this result to the earlier polynomial output given in Figure 3-5 and identify that the results are quite different. In this case, the first vector (group) is the normalized neutron power density defined using equation 2-10 and the hand calculated verification (Excel) is shown in Table 3.26. The second vector (group) is the normalized gamma power density also defined using equation 2-10 and the verification is shown in Table 3.27. The third vector (group) is the un-normalized fast flux defined using equation 2-11 and the verification is shown in Table 3.28. A quick review of the reported differences in each table shows the hand calculation is within 10^{-8} of the VARPOW result which is consistent with the truncation error of the input to Excel.

```
# This is the VARPOW material power density (watts/cc) for all active meshes
# MatPowerDensity(6,NINTXY,NINTK) NINTXY=    16 NINTK=     1
 1.055293873E-04  1.563679780E-07  1.306086137E-08  0.000000000E+00  0.000000000E+00  0.000000000E+00
 7.429551985E-05  1.112820089E-07  9.222351167E-09  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  2.138881987E-07  2.087675275E-09  0.000000000E+00  0.000000000E+00  0.000000000E+00
 9.447064968E-07  7.714741513E-09  4.053806883E-10  0.000000000E+00  0.000000000E+00  0.000000000E+00
 7.429551985E-05  1.112820089E-07  9.222351167E-09  0.000000000E+00  0.000000000E+00  0.000000000E+00
 5.285383466E-05  8.004133702E-08  6.582240861E-09  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  1.587822811E-07  1.553876278E-09  0.000000000E+00  0.000000000E+00  0.000000000E+00
 7.082143369E-07  5.848761627E-09  3.068853052E-10  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  2.138881987E-07  2.087675275E-09  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  1.587822811E-07  1.553876278E-09  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  7.976969097E-08  7.952051486E-10  0.000000000E+00  0.000000000E+00  0.000000000E+00
 3.760282271E-07  3.090325963E-09  1.614442501E-10  0.000000000E+00  0.000000000E+00  0.000000000E+00
 9.447064968E-07  7.714741513E-09  4.053806883E-10  0.000000000E+00  0.000000000E+00  0.000000000E+00
 7.082143369E-07  5.848761627E-09  3.068853052E-10  0.000000000E+00  0.000000000E+00  0.000000000E+00
 3.760282271E-07  3.090325963E-09  1.614442501E-10  0.000000000E+00  0.000000000E+00  0.000000000E+00
 1.016920005E-07  7.979298242E-10  4.186505647E-11  0.000000000E+00  0.000000000E+00  0.000000000E+00
```

Figure 3-7. Excerpt of ISOTXS Based 'MaterialPower.out' Calculated by VARPOW

Table 3.24. Verification of the ISOTXS Based Power Density Output from 'MaterialPower.out'

mesh	VARPOW Results			Relative Difference between Excel and VARPOW		
	fuel	cladding	coolant	fuel	cladding	coolant
1	1.055294E-04	1.563680E-07	1.306086E-08	-1.08E-10	4.98E-08	1.85E-08
2	7.429552E-05	1.112820E-07	9.222351E-09	6.31E-09	4.73E-08	1.78E-08
3	0.000000E+00	2.138882E-07	2.087675E-09	0	-4.27E-08	2.49E-08
4	9.447065E-07	7.714742E-09	4.053807E-10	6.10E-08	-7.98E-08	-2.28E-08
5	7.429552E-05	1.112820E-07	9.222351E-09	6.31E-09	4.73E-08	1.78E-08
6	5.285383E-05	8.004134E-08	6.582241E-09	1.32E-08	4.40E-08	1.75E-08
7	0.000000E+00	1.587823E-07	1.553876E-09	0	-4.59E-08	2.43E-08
8	7.082143E-07	5.848762E-09	3.068853E-10	6.08E-08	-8.09E-08	-2.31E-08
9	0.000000E+00	2.138882E-07	2.087675E-09	0	-4.27E-08	2.49E-08
10	0.000000E+00	1.587823E-07	1.553876E-09	0	-4.59E-08	2.43E-08
11	0.000000E+00	7.976969E-08	7.952051E-10	0	-5.90E-08	2.09E-08
12	3.760282E-07	3.090326E-09	1.614443E-10	6.16E-08	-7.95E-08	-2.28E-08
13	9.447065E-07	7.714742E-09	4.053807E-10	6.10E-08	-7.98E-08	-2.28E-08
14	7.082143E-07	5.848762E-09	3.068853E-10	6.08E-08	-8.09E-08	-2.31E-08
15	3.760282E-07	3.090326E-09	1.614443E-10	6.16E-08	-7.95E-08	-2.28E-08
16	1.016920E-07	7.979298E-10	4.186506E-11	6.30E-08	-7.40E-08	-2.12E-08

```
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      1
[NHFLUX]...XY Node; Nodal moments ->
    1  1.056988161E-04 -4.818396626E-06 -4.818396626E-06 -1.176593074E-06  0.000000000E+00 -1.176593074E-06
    2  7.441602421E-05 -1.224983219E-05 -3.306251499E-06 -4.074992927E-07  0.000000000E+00 -8.127450617E-07
    3  2.159758740E-07 -6.606429698E-08 -9.078370631E-09 -4.451238565E-09  0.000000000E+00 -2.201470869E-09
    4  9.528266190E-07 -7.205991299E-07 -3.809327430E-08  1.759301650E-07  0.000000000E+00 -1.265554313E-08
    5  7.441602421E-05 -1.224983219E-05 -3.306251499E-06 -4.074992927E-07  0.000000000E+00 -8.127450617E-07
    6  5.294045824E-05 -8.374968636E-06 -8.374968636E-06 -2.568161443E-07  0.000000000E+00 -2.568161443E-07
    7  1.603361574E-07 -4.762905064E-08 -2.103996370E-08 -3.872401168E-09  0.000000000E+00 -6.481255959E-10
    8  7.143699839E-07 -5.348799835E-07 -8.953166989E-08  1.290762356E-07  0.000000000E+00 -4.872413615E-09
    9  2.159758740E-07 -6.606429698E-08 -9.078370631E-09 -4.451238565E-09  0.000000000E+00 -2.201470869E-09
   10  1.603361574E-07 -4.762905064E-08 -2.103996370E-08 -3.872401168E-09  0.000000000E+00 -6.481255959E-10
   11  8.056489612E-08 -2.515432977E-08 -2.515432977E-08 -7.553159824E-10  0.000000000E+00 -7.553159824E-10
   12  3.792799974E-07 -2.723839419E-07 -9.329353221E-08  6.081355587E-08  0.000000000E+00  3.368654353E-09
   13  9.528266190E-07 -7.205991299E-07 -3.809327430E-08  1.759301650E-07  0.000000000E+00 -1.265554313E-08
   14  7.143699839E-07 -5.348799835E-07 -8.953166989E-08  1.290762356E-07  0.000000000E+00 -4.872413615E-09
   15  3.792799974E-07 -2.723839419E-07 -9.329353221E-08  6.081355587E-08  0.000000000E+00  3.368654353E-09
   16  1.025317954E-07 -6.051812231E-08 -6.051812231E-08  7.992200034E-09  0.000000000E+00  7.992200034E-09
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      2
[NHFLUX]...XY Node; Nodal moments ->
    1  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
    2  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
    3  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
    4  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
    5  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
    6  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
    7  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
    8  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
    9  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
   10  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
   11  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
   12  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
   13  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
   14  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
   15  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
   16  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      3
[NHFLUX]...XY Node; Nodal moments ->
    1  5.946850657E+08 -2.788853840E+07 -2.788853840E+07 -6.985667977E+06  0.000000000E+00 -6.985667977E+06
    2  4.042566862E+08 -8.414683727E+07 -1.861705362E+07 -8.605750020E+06  0.000000000E+00 -4.601904319E+06
    3  1.112239225E+08 -5.798819388E+07 -5.230005499E+06  1.234514618E+07  0.000000000E+00 -1.585116457E+06
    4  1.556628816E+07 -1.054501872E+07 -6.666018288E+05  2.038956084E+06  0.000000000E+00 -2.090117978E+05
    5  4.042566862E+08 -8.414683727E+07 -1.861705362E+07 -8.605750020E+06  0.000000000E+00 -4.601904319E+06
    6  2.766038065E+08 -5.685527407E+07 -5.685527407E+07 -5.974422242E+06  0.000000000E+00 -5.974422242E+06
    7  7.765253720E+07 -3.956119942E+07 -1.316669295E+07  8.315418658E+06  0.000000000E+00 -8.215417914E+05
    8  1.148705748E+07 -7.584212975E+06 -1.473880639E+06  1.386839898E+06  0.000000000E+00 -4.273586275E+04
    9  1.112239225E+08 -5.798819388E+07 -5.230005499E+06  1.234514618E+07  0.000000000E+00 -1.585116457E+06
   10  7.765253720E+07 -3.956119942E+07 -1.316669295E+07  8.315418658E+06  0.000000000E+00 -8.215417914E+05
   11  3.054760522E+07 -1.108706509E+07 -1.108706509E+07  1.457536938E+06  0.000000000E+00  1.457536938E+06
   12  6.188411251E+06 -3.976097199E+06 -1.473561412E+06  6.834298969E+05  0.000000000E+00  4.381291622E+04
   13  1.556628816E+07 -1.054501872E+07 -6.666018288E+05  2.038956084E+06  0.000000000E+00 -2.090117978E+05
   14  1.148705748E+07 -7.584212975E+06 -1.473880639E+06  1.386839898E+06  0.000000000E+00 -4.273586275E+04
   15  6.188411251E+06 -3.976097199E+06 -1.473561412E+06  6.834298969E+05  0.000000000E+00  4.381291622E+04
   16  1.781474098E+06 -9.898046974E+05 -9.898046974E+05  1.065396643E+05  0.000000000E+00  1.065396643E+05
```

Figure 3-8. PrintTables Excerpt for ISOTXS Based 'Output.VARPOW' (iOption=P)

Table 3.25. Verification of the ISOTXS Based Neutron Power Density from 'Output.VARPOW' (iOption=P)

Data	mesh	Moments (m)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	1.05699E-04	-4.81840E-06	-4.81840E-06	-1.17659E-06	0.00E+00	-1.17659E-06
	2	7.44160E-05	-1.22498E-05	-3.30625E-06	-4.07499E-07	0.00E+00	-8.12745E-07
	3	2.15976E-07	-6.60643E-08	-9.07837E-09	-4.45124E-09	0.00E+00	-2.20147E-09
	4	9.52827E-07	-7.20599E-07	-3.80933E-08	1.75930E-07	0.00E+00	-1.26555E-08
	5	7.44160E-05	-1.22498E-05	-3.30625E-06	-4.07499E-07	0.00E+00	-8.12745E-07
	6	5.29405E-05	-8.37497E-06	-8.37497E-06	-2.56816E-07	0.00E+00	-2.56816E-07
	7	1.60336E-07	-4.76291E-08	-2.10400E-08	-3.87240E-09	0.00E+00	-6.48126E-10
	8	7.14370E-07	-5.34880E-07	-8.95317E-08	1.29076E-07	0.00E+00	-4.87241E-09
	9	2.15976E-07	-6.60643E-08	-9.07837E-09	-4.45124E-09	0.00E+00	-2.20147E-09
	10	1.60336E-07	-4.76291E-08	-2.10400E-08	-3.87240E-09	0.00E+00	-6.48126E-10
	11	8.05649E-08	-2.51543E-08	-2.51543E-08	-7.55316E-10	0.00E+00	-7.55316E-10
	12	3.79280E-07	-2.72384E-07	-9.32935E-08	6.08136E-08	0.00E+00	3.36865E-09
	13	9.52827E-07	-7.20599E-07	-3.80933E-08	1.75930E-07	0.00E+00	-1.26555E-08
	14	7.14370E-07	-5.34880E-07	-8.95317E-08	1.29076E-07	0.00E+00	-4.87241E-09
	15	3.79280E-07	-2.72384E-07	-9.32935E-08	6.08136E-08	0.00E+00	3.36865E-09
	16	1.02532E-07	-6.05181E-08	-6.05181E-08	7.99220E-09	0.00E+00	7.99220E-09
Rela. Diff.	1	3.40E-10	-3.81E-09	-3.81E-09	-6.16E-09	0	-6.16E-09
	2	6.37E-09	-3.61E-08	1.52E-09	-3.87E-07	0	3.63E-09
	3	-4.22E-08	-3.80E-09	-3.86E-08	-5.13E-07	0	-1.98E-08
	4	5.98E-08	5.47E-08	6.06E-08	4.22E-08	0	5.73E-08
	5	6.37E-09	-3.61E-08	1.52E-09	-3.87E-07	0	3.63E-09
	6	1.32E-08	-3.23E-08	-3.23E-08	-4.21E-07	0	-4.21E-07
	7	-4.53E-08	-7.23E-09	-2.60E-08	-4.47E-07	0	1.06E-07
	8	5.95E-08	5.43E-08	5.96E-08	3.99E-08	0	4.49E-08
	9	-4.22E-08	-3.80E-09	-3.86E-08	-5.13E-07	0	-1.98E-08
	10	-4.53E-08	-7.23E-09	-2.60E-08	-4.47E-07	0	1.06E-07
	11	-5.82E-08	-5.89E-08	-5.89E-08	-4.63E-07	0	-4.63E-07
	12	6.02E-08	5.61E-08	5.98E-08	4.38E-08	0	4.52E-08
	13	5.98E-08	5.47E-08	6.06E-08	4.22E-08	0	5.73E-08
	14	5.95E-08	5.43E-08	5.96E-08	3.99E-08	0	4.49E-08
	15	6.02E-08	5.61E-08	5.98E-08	4.38E-08	0	4.52E-08
	16	6.18E-08	6.08E-08	6.08E-08	5.28E-08	0	5.28E-08

$$I(m) = \int_{-0.5}^{0.5} s^m \, ds = \frac{.5^{m+1} - (-.5)^{m+1}}{m+1} \qquad I(m) := \frac{.5^{(m+1.)}}{(m+1.)} - 1. \cdot \frac{(-.5)^{(m+1.)}}{(m+1.)}$$

$$Mono := \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 2 & 0 \\ 1 & 1 \\ 0 & 2 \end{bmatrix}$$

$$M := \left| \begin{array}{l} Temp \leftarrow 0 \\ \text{for } i \in 1 .. rows(Mono) \\ \quad \text{for } j \in 1 .. rows(Mono) \\ \quad\quad Temp_{i,j} \leftarrow I\left(Mono_{i,1} + Monc_{j,1}\right) \cdot I\left(Mono_{i,2} + Monc_{j,2}\right) \\ Temp \end{array} \right.$$

$$M = \begin{bmatrix} 1 & 0 & 0 & 0.083333 & 0 & 0.083333 \\ 0 & 0.083333 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.083333 & 0 & 0 & 0 \\ 0.083333 & 0 & 0 & 0.0125 & 0 & 6.944444 \cdot 10^{-3} \\ 0 & 0 & 0 & 0 & 6.944444 \cdot 10^{-3} & 0 \\ 0.083333 & 0 & 0 & 6.944444 \cdot 10^{-3} & 0 & 0.0125 \end{bmatrix}$$

$$F := cholesky(M)^{-1^T} \qquad \left(F^T\right)^{-1} \cdot F^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0.083333 & 0 & 0.083333 \\ 0 & 0.083333 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.083333 & 0 & 0 & 0 \\ 0.083333 & 0 & 0 & 0.0125 & 0 & 6.944444 \cdot 10^{-3} \\ 0 & 0 & 0 & 0 & 6.944444 \cdot 10^{-3} & 0 \\ 0.083333 & 0 & 0 & 6.944444 \cdot 10^{-3} & 0 & 0.0125 \end{bmatrix}$$

$$F = \begin{bmatrix} 1 & 0 & 0 & -1.118034 & 0 & -1.118034 \\ 0 & 3.464102 & 0 & 0 & 0 & 0 \\ 0 & 0 & 3.464102 & 0 & 0 & 0 \\ 0 & 0 & 0 & 13.416408 & 0 & 0 \\ 0 & 0 & 0 & 0 & 12 & 0 \\ 0 & 0 & 0 & 0 & 0 & 13.416408 \end{bmatrix} \qquad F^T = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3.464102 & 0 & 0 & 0 & 0 \\ 0 & 0 & 3.464102 & 0 & 0 & 0 \\ -1.118034 & 0 & 0 & 13.416408 & 0 & 0 \\ 0 & 0 & 0 & 0 & 12 & 0 \\ -1.118034 & 0 & 0 & 0 & 0 & 13.416408 \end{bmatrix}$$

Figure 3-9. Example Calculation of the Polynomial to Monomial Coefficient Matrix $\hat{F}$

```
# This is the VARPOW associated VARIANT exponents for the monomial basis X^M * Y^N * Z^O
# NumDimensions=  2 Domain type=  1 ITRORD=     2 IAPRX=    20 X,Y,Z Orders=  2  2  2 ExpansionTerms    6
#  M   N   O
   0   0   0
   1   0   0
   0   1   0
   2   0   0
   1   1   0
   0   2   0
# This is the coefficient matrix to construct polynomials from the monomials
 1.000000000E+00  0.000000000E+00  0.000000000E+00 -1.118033989E+00  0.000000000E+00 -1.118033989E+00
 0.000000000E+00  3.464101615E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00  3.464101615E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00  0.000000000E+00  1.341640786E+01  0.000000000E+00  0.000000000E+00
 0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  1.200000000E+01  0.000000000E+00
 0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  0.000000000E+00  1.341640786E+01
```

Figure 3-10. Excerpt of the VariantMonoExponents File

```
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      1
[NHFLUX]...XY Node; Nodal moments ->
    1  1.024897945E+00 -1.579505115E-01 -1.579505115E-01 -1.493876718E-01  0.000000000E+00 -1.493876718E-01
    2  1.018465432E+00 -5.716459801E-01 -1.539479857E-01 -7.504245168E-02  0.000000000E+00 -1.465427315E-01
    3  9.194380293E-01 -1.642253562E+00 -1.587702709E-01  1.146353475E+00  0.000000000E+00 -1.796098257E-01
    4  8.203177364E-01 -2.562938043E+00 -1.408772521E-01  2.335277171E+00  0.000000000E+00 -1.790900076E-01
    5  1.018465432E+00 -5.716459801E-01 -1.539479857E-01 -7.504245168E-02  0.000000000E+00 -1.465427315E-01
    6  1.011098530E+00 -5.494329451E-01 -5.494329451E-01 -6.659117981E-02  0.000000000E+00 -6.659117981E-02
    7  9.202146845E-01 -1.596280473E+00 -5.578905594E-01  1.081703500E+00  0.000000000E+00 -1.242797137E-01
    8  8.179673799E-01 -2.530450019E+00 -4.366937325E-01  2.266825469E+00  0.000000000E+00 -8.243402725E-02
    9  9.194380293E-01 -1.642253562E+00 -1.587702709E-01  1.146353475E+00  0.000000000E+00 -1.796098257E-01
   10  9.202146845E-01 -1.596280473E+00 -5.578905594E-01  1.081703500E+00  0.000000000E+00 -1.242797137E-01
   11  9.234950879E-01 -1.198000219E+00 -1.198000219E+00  4.590294727E-01  0.000000000E+00  4.590294727E-01
   12  8.225541580E-01 -2.431425336E+00 -8.459216309E-01  2.014607449E+00  0.000000000E+00  1.147426551E-01
   13  8.203177364E-01 -2.562938043E+00 -1.408772521E-01  2.335277171E+00  0.000000000E+00 -1.790900076E-01
   14  8.179673799E-01 -2.530450019E+00 -4.366937325E-01  2.266825469E+00  0.000000000E+00 -8.243402725E-02
   15  8.225541580E-01 -2.431425336E+00 -8.459216309E-01  2.014607449E+00  0.000000000E+00  1.147426551E-01
   16  8.349942314E-01 -2.015195347E+00 -2.015195347E+00  9.900346114E-01  0.000000000E+00  9.900346114E-01
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      2
[NHFLUX]...XY Node; Nodal moments ->
    1  1.032433152E+00 -1.701378433E-01 -1.701378433E-01 -1.945989095E-01  0.000000000E+00 -1.945989095E-01
    2  1.054882525E+00 -7.179472327E-01 -1.659461472E-01 -4.756239977E-01  0.000000000E+00 -1.829663072E-01
    3  6.342229125E-01 -2.275870274E+00 -1.529183637E-01  4.628065299E+00  0.000000000E+00 -2.387402497E-01
    4  7.917557143E-01 -2.736362578E+00 -1.353842113E-01  2.683947947E+00  0.000000000E+00 -1.850165191E-01
    5  1.054882525E+00 -7.179472327E-01 -1.659461472E-01 -4.756239977E-01  0.000000000E+00 -1.829663072E-01
    6  1.081237035E+00 -7.012822111E-01 -7.012822111E-01 -4.874222095E-01  0.000000000E+00 -4.874222095E-01
    7  6.378230392E-01 -2.203269083E+00 -5.279561043E-01  4.528076605E+00  0.000000000E+00 -1.819530758E-01
    8  7.974379623E-01 -2.705463524E+00 -4.422150172E-01  2.566274940E+00  0.000000000E+00 -1.355304883E-01
    9  6.342229125E-01 -2.275870274E+00 -1.529183637E-01  4.628065299E+00  0.000000000E+00 -2.387402497E-01
   10  6.378230392E-01 -2.203269083E+00 -5.279561043E-01  4.528076605E+00  0.000000000E+00 -1.819530758E-01
   11  7.813949050E-01 -1.061644120E+00 -1.061644120E+00  1.311630570E+00  0.000000000E+00  1.311630570E+00
   12  8.514357440E-01 -2.427366715E+00 -8.986230973E-01  1.523854373E+00  0.000000000E+00  2.589166989E-01
   13  7.917557143E-01 -2.736362578E+00 -1.353842113E-01  2.683947947E+00  0.000000000E+00 -1.850165191E-01
   14  7.974379623E-01 -2.705463524E+00 -4.422150172E-01  2.566274940E+00  0.000000000E+00 -1.355304883E-01
   15  8.514357440E-01 -2.427366715E+00 -8.986230973E-01  1.523854373E+00  0.000000000E+00  2.589166989E-01
   16  8.359626072E-01 -2.097865142E+00 -2.097865142E+00  9.842243570E-01  0.000000000E+00  9.842243570E-01
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      3
[NHFLUX]...XY Node; Nodal moments ->
    1  6.103054942E+08 -9.660873093E+07 -9.660873093E+07 -9.372257079E+07  0.000000000E+00 -9.372257079E+07
    2  4.190232927E+08 -2.914931949E+08 -6.449136552E+07 -1.154582523E+08  0.000000000E+00 -6.174102531E+07
    3  9.919384354E+07 -2.008769961E+08 -1.811727050E+07  1.656275163E+08  0.000000000E+00 -2.126656890E+07
    4  1.352034825E+07 -3.652901636E+07 -2.309176472E+06  2.735546645E+07  0.000000000E+00 -2.804187528E+06
    5  4.190232927E+08 -2.914931949E+08 -6.449136552E+07 -1.154582523E+08  0.000000000E+00 -6.174102531E+07
    6  2.899630208E+08 -1.969524467E+08 -1.969524467E+08 -8.015528556E+07  0.000000000E+00 -8.015528556E+07
    7  6.927412815E+07 -1.370440148E+08 -4.561076233E+07  1.115630483E+08  0.000000000E+00 -1.102213975E+07
    8  9.984303483E+06 -2.627248442E+07 -5.105672303E+06  1.860640972E+07  0.000000000E+00 -5.733617651E+05
    9  9.919384354E+07 -2.008769961E+08 -1.811727050E+07  1.656275163E+08  0.000000000E+00 -2.126656890E+07
   10  6.927412815E+07 -1.370440148E+08 -4.561076233E+07  1.115630483E+08  0.000000000E+00 -1.102213975E+07
   11  2.728845354E+07 -3.840672008E+07 -3.840672008E+07  1.955491004E+07  0.000000000E+00  1.955491004E+07
   12  5.375329068E+06 -1.377360473E+07 -5.104566467E+06  9.169174243E+06  0.000000000E+00  5.878119537E+05
   13  1.352034825E+07 -3.652901636E+07 -2.309176472E+06  2.735546645E+07  0.000000000E+00 -2.804187528E+06
   14  9.984303483E+06 -2.627248442E+07 -5.105672303E+06  1.860640972E+07  0.000000000E+00 -5.733617651E+05
   15  5.375329068E+06 -1.377360473E+07 -5.104566467E+06  9.169174243E+06  0.000000000E+00  5.878119537E+05
   16  1.543244166E+06 -3.428784051E+06 -3.428784051E+06  1.429379589E+06  0.000000000E+00  1.429379589E+06
```

Figure 3-11. PrintTables Excerpt for PMATRX Based 'Output.VARPOW' (iOption=M)

Table 3.26. Verification of the PMATRX Based Neutron Power Density from 'Output.VARPOW' (iOption=M)

	mesh	Monomial Moments (*j*)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	1.02490E+00	-1.57951E-01	-1.57951E-01	-1.49388E-01	0.00E+00	-1.49388E-01
	2	1.01847E+00	-5.71646E-01	-1.53948E-01	-7.50425E-02	0.00E+00	-1.46543E-01
	3	9.19438E-01	-1.64225E+00	-1.58770E-01	1.14635E+00	0.00E+00	-1.79610E-01
	4	8.20318E-01	-2.56294E+00	-1.40877E-01	2.33528E+00	0.00E+00	-1.79090E-01
	5	1.01847E+00	-5.71646E-01	-1.53948E-01	-7.50425E-02	0.00E+00	-1.46543E-01
	6	1.01110E+00	-5.49433E-01	-5.49433E-01	-6.65912E-02	0.00E+00	-6.65912E-02
	7	9.20215E-01	-1.59628E+00	-5.57891E-01	1.08170E+00	0.00E+00	-1.24280E-01
	8	8.17967E-01	-2.53045E+00	-4.36694E-01	2.26683E+00	0.00E+00	-8.24340E-02
	9	9.19438E-01	-1.64225E+00	-1.58770E-01	1.14635E+00	0.00E+00	-1.79610E-01
	10	9.20215E-01	-1.59628E+00	-5.57891E-01	1.08170E+00	0.00E+00	-1.24280E-01
	11	9.23495E-01	-1.19800E+00	-1.19800E+00	4.59029E-01	0.00E+00	4.59029E-01
	12	8.22554E-01	-2.43143E+00	-8.45922E-01	2.01461E+00	0.00E+00	1.14743E-01
	13	8.20318E-01	-2.56294E+00	-1.40877E-01	2.33528E+00	0.00E+00	-1.79090E-01
	14	8.17967E-01	-2.53045E+00	-4.36694E-01	2.26683E+00	0.00E+00	-8.24340E-02
	15	8.22554E-01	-2.43143E+00	-8.45922E-01	2.01461E+00	0.00E+00	1.14743E-01
	16	8.34994E-01	-2.01520E+00	-2.01520E+00	9.90035E-01	0.00E+00	9.90035E-01
Rela. Diff.	1	3.10E-10	8.38E-11	8.38E-11	1.01E-10	0	1.01E-10
	2	-1.34E-10	-4.06E-09	-1.97E-10	-1.35E-08	0	4.64E-10
	3	-3.09E-09	1.02E-08	2.24E-09	2.94E-08	0	6.05E-09
	4	-6.55E-09	1.09E-08	-1.09E-08	2.66E-08	0	-4.96E-09
	5	-1.34E-10	-4.06E-09	-1.97E-10	-1.35E-08	0	4.64E-10
	6	-1.13E-10	-4.24E-09	-4.24E-09	-8.02E-09	0	-8.02E-09
	7	-3.02E-09	1.03E-08	5.35E-09	3.16E-08	0	1.35E-08
	8	-6.88E-09	1.29E-08	-3.83E-09	3.12E-08	0	6.03E-08
	9	-3.09E-09	1.02E-08	2.24E-09	2.94E-08	0	6.05E-09
	10	-3.02E-09	1.03E-08	5.35E-09	3.16E-08	0	1.35E-08
	11	-3.06E-09	4.30E-09	4.30E-09	3.62E-08	0	3.62E-08
	12	-6.85E-09	1.24E-08	4.36E-09	3.20E-08	0	1.47E-08
	13	-6.55E-09	1.09E-08	-1.09E-08	2.66E-08	0	-4.96E-09
	14	-6.88E-09	1.29E-08	-3.83E-09	3.12E-08	0	6.03E-08
	15	-6.85E-09	1.24E-08	4.36E-09	3.20E-08	0	1.47E-08
	16	-5.89E-09	8.62E-09	8.62E-09	2.94E-08	0	2.94E-08

Table 3.27. Verification of the PMATRX Based Gamma Power Density from 'Output.VARPOW' (iOption=M)

	mesh	Monomial Moments (j)					
		0	1	2	3	4	5
VARPOW power density (Wcm^3)	1	6.23624E-06	-3.06290E-07	-3.06290E-07	-9.04538E-08	0.00E+00	-9.04538E-08
	2	4.32614E-06	-8.96609E-07	-2.07242E-07	-1.53366E-07	0.00E+00	-5.89978E-08
	3	5.54040E-07	-3.63997E-07	-2.44574E-08	1.91119E-07	0.00E+00	-9.85895E-09
	4	2.59149E-07	-2.04707E-07	-1.01281E-08	5.18427E-08	0.00E+00	-3.57375E-09
	5	4.32614E-06	-8.96609E-07	-2.07242E-07	-1.53366E-07	0.00E+00	-5.89978E-08
	6	3.02710E-06	-6.12814E-07	-6.12814E-07	-1.09975E-07	0.00E+00	-1.09975E-07
	7	3.97005E-07	-2.52507E-07	-6.05067E-08	1.33990E-07	0.00E+00	-5.38418E-09
	8	1.95080E-07	-1.52357E-07	-2.49032E-08	3.73146E-08	0.00E+00	-1.97066E-09
	9	5.54040E-07	-3.63997E-07	-2.44574E-08	1.91119E-07	0.00E+00	-9.85895E-09
	10	3.97005E-07	-2.52507E-07	-6.05067E-08	1.33990E-07	0.00E+00	-5.38418E-09
	11	1.60119E-07	-4.90716E-08	-4.90716E-08	1.56537E-08	0.00E+00	1.56537E-08
	12	1.00196E-07	-7.02093E-08	-2.59918E-08	1.13804E-08	0.00E+00	1.93363E-09
	13	2.59149E-07	-2.04707E-07	-1.01281E-08	5.18427E-08	0.00E+00	-3.57375E-09
	14	1.95080E-07	-1.52357E-07	-2.49032E-08	3.73146E-08	0.00E+00	-1.97066E-09
	15	1.00196E-07	-7.02093E-08	-2.59918E-08	1.13804E-08	0.00E+00	1.93363E-09
	16	2.66449E-08	-1.61362E-08	-1.61362E-08	1.95467E-09	0.00E+00	1.95467E-09
Rela. Diff.	1	-3.63E-10	-6.93E-11	-6.93E-11	7.10E-10	0	7.10E-10
	2	6.51E-10	1.17E-09	6.49E-10	5.86E-09	0	9.18E-10
	3	-1.75E-10	-8.34E-11	1.28E-10	-1.54E-10	0	-5.18E-10
	4	3.79E-11	-1.57E-10	-2.73E-10	-5.18E-10	0	-2.09E-10
	5	6.51E-10	1.17E-09	6.49E-10	5.86E-09	0	9.18E-10
	6	3.92E-10	1.26E-09	1.26E-09	5.64E-09	0	5.64E-09
	7	-1.28E-10	-9.65E-11	-9.58E-11	-2.88E-10	0	-5.05E-10
	8	-9.01E-12	3.10E-11	-2.54E-11	-2.64E-10	0	-1.04E-10
	9	-1.75E-10	-8.34E-11	1.28E-10	-1.54E-10	0	-5.18E-10
	10	-1.28E-10	-9.65E-11	-9.58E-11	-2.88E-10	0	-5.05E-10
	11	-1.17E-10	1.71E-10	1.71E-10	-1.79E-10	0	-1.79E-10
	12	-6.12E-10	2.71E-10	-1.36E-10	3.74E-09	0	-1.58E-09
	13	3.79E-11	-1.57E-10	-2.73E-10	-5.18E-10	0	-2.09E-10
	14	-9.01E-12	3.10E-11	-2.54E-11	-2.64E-10	0	-1.04E-10
	15	-6.12E-10	2.71E-10	-1.36E-10	3.74E-09	0	-1.58E-09
	16	-2.47E-10	-8.29E-11	-8.29E-11	4.58E-10	0	4.58E-10

Table 3.28. Verification of the PMATRX Based Fast Flux from 'Output.VARPOW' (iOption=M)

	mesh	Monomial Moments (*j*)					
		0	1	2	3	4	5
VARPOW Fast Neutron Flux	1	6.10305E+08	-9.66087E+07	-9.66087E+07	-9.37226E+07	0.00E+00	-9.37226E+07
	2	4.19023E+08	-2.91493E+08	-6.44914E+07	-1.15458E+08	0.00E+00	-6.17410E+07
	3	9.91938E+07	-2.00877E+08	-1.81173E+07	1.65628E+08	0.00E+00	-2.12666E+07
	4	1.35203E+07	-3.65290E+07	-2.30918E+06	2.73555E+07	0.00E+00	-2.80419E+06
	5	4.19023E+08	-2.91493E+08	-6.44914E+07	-1.15458E+08	0.00E+00	-6.17410E+07
	6	2.89963E+08	-1.96952E+08	-1.96952E+08	-8.01553E+07	0.00E+00	-8.01553E+07
	7	6.92741E+07	-1.37044E+08	-4.56108E+07	1.11563E+08	0.00E+00	-1.10221E+07
	8	9.98430E+06	-2.62725E+07	-5.10567E+06	1.86064E+07	0.00E+00	-5.73362E+05
	9	9.91938E+07	-2.00877E+08	-1.81173E+07	1.65628E+08	0.00E+00	-2.12666E+07
	10	6.92741E+07	-1.37044E+08	-4.56108E+07	1.11563E+08	0.00E+00	-1.10221E+07
	11	2.72885E+07	-3.84067E+07	-3.84067E+07	1.95549E+07	0.00E+00	1.95549E+07
	12	5.37533E+06	-1.37736E+07	-5.10457E+06	9.16917E+06	0.00E+00	5.87812E+05
	13	1.35203E+07	-3.65290E+07	-2.30918E+06	2.73555E+07	0.00E+00	-2.80419E+06
	14	9.98430E+06	-2.62725E+07	-5.10567E+06	1.86064E+07	0.00E+00	-5.73362E+05
	15	5.37533E+06	-1.37736E+07	-5.10457E+06	9.16917E+06	0.00E+00	5.87812E+05
	16	1.54324E+06	-3.42878E+06	-3.42878E+06	1.42938E+06	0.00E+00	1.42938E+06
Rela. Diff.	1	-8.55E-10	-7.72E-10	-7.72E-10	-1.16E-09	0	-1.16E-09
	2	-1.03E-09	-6.01E-10	-7.00E-10	-5.95E-10	0	-1.32E-09
	3	-2.25E-09	-1.09E-09	-1.88E-09	3.72E-10	0	-1.62E-09
	4	-1.89E-09	-2.60E-09	-2.00E-09	-3.82E-09	0	-2.45E-09
	5	-1.03E-09	-6.01E-10	-7.00E-10	-5.95E-10	0	-1.32E-09
	6	-8.44E-10	-4.91E-10	-4.91E-10	-1.35E-10	0	-1.35E-10
	7	-2.32E-09	-8.39E-10	-1.38E-09	-1.35E-10	0	-9.76E-10
	8	-2.36E-09	-2.85E-09	-2.44E-09	-3.96E-09	0	-5.95E-09
	9	-2.25E-09	-1.09E-09	-1.88E-09	3.72E-10	0	-1.62E-09
	10	-2.32E-09	-8.39E-10	-1.38E-09	-1.35E-10	0	-9.76E-10
	11	-2.80E-09	-2.11E-09	-2.11E-09	-7.13E-11	0	-7.13E-11
	12	-2.22E-09	-2.76E-09	-2.26E-09	-4.01E-09	0	-3.13E-09
	13	-1.89E-09	-2.60E-09	-2.00E-09	-3.82E-09	0	-2.45E-09
	14	-2.36E-09	-2.85E-09	-2.44E-09	-3.96E-09	0	-5.95E-09
	15	-2.22E-09	-2.76E-09	-2.26E-09	-4.01E-09	0	-3.13E-09
	16	-1.59E-09	-2.31E-09	-2.31E-09	-3.15E-09	0	-3.15E-09

The preceding hand calculation demonstrates that the equations VARPOW are using are consistent with those shown here and in the VARPOW manual [1]. Further demonstration on how the monomial distribution output is generated and that the output VARPOW produces is consistent with expectations. The companion Excel document is provided to show how the output excerpts from PrintTables of PMATRX, NHFLUX, and GHFLUX (or ISOTXS and NHFLUX) can be combined to get the power density output. In all of that work, the knowledge of how materials are assigned to the domain and atom density details was hard-wired into the Excel calculations.

This was a simple problem with 16 meshes, 4 neutron energy groups, 21 group gamma groups, and just a few isotopes. The practical use cases for VARPOW will have hundreds of compositions each with tens of isotopes that are assigned to ~10000 meshes. It is likely that each spatial mesh will have order 80 spatial moments combined with a 33 neutron energy group and 21 (or 94) gamma group structures. Needless to say, it is untenable to fully verify such realistic problems via a hand calculation. As a consequence, a simple Fortran program that duplicates the VARPOW work was written, and is provided with the verification test problems. That program can thoroughly check the set of test problems covered in this report against the 'MaterialPower.out' and 'Output.VARPOW' files from VARPOW. The duplicate program independently calculates the quantities in those output files and it outputs the maximum difference found with respect to the VARPOW results. It is noted that the duplicate program still requires input to be constructed for the comparison itself which is mostly taken from PrintTable output and some hand made composition details and their mesh assignments.

For the oxide fuel with sodium coolant test case covered in this section, the maximum relative differences between the duplicate program and VARPOW are shown in Table 3.29. As seen, all iOutput options of VARPOW were checked and those options hand calculated in Excel and detailed above are shaded. From the results, one can see that that duplicate program reproduces the VARPOW results within the truncation error of the inputs provided to the duplicate program similar to that observed with the hand calculations above. For the polynomial basis results (iOutput option P or T), the maximum relative difference was found to be on the order of 10^{-6} while the monomial basis results are on the order of 10^{-9}. The reason for the difference between these two types of output is that the monomial basis results are normalized by mesh which mitigates the truncation error issues in the duplicate program calculation as it appears in the numerator and denominator.

Table 3.29. Maximum Relative Difference for Oxide Fuel and Sodium Coolant Case

Input	iOutput	Maximum relative difference	
		Output.VARPOW	MaterialPower.out
ISOTXS	M	1.02999E-09	8.12622E-08
	S	8.16759E-10	
	P	5.39357E-07	
	T	1.80144E-06	
PMATRX	M	7.83633E-10	1.71643E-07
	S	1.03673E-09	
	P	1.35246E-07	
	T	2.20563E-07	

3.1.2 Two-Dimensional Simple Problem Using Different Fuel and Coolant Isotopes

In this section the same two-dimesional problem described by Figure 3-1 is used with different compositions to test out the other iTypeFuel and iTypeCool input options of VARPOW. Table 3.30 shows the isotopic atom densities of the five test case. As noted in Figure 1-1, VARPOW is stated to handle Zr-alloyed (1), oxide (2), nitride (3) and aluminium alloyed (4) fuel with respect to 'iTypeFuel' input options. Similarly, VARPOW states it can handle Na (1), NaCl (2), Pb (3), Pb-Bi (4), and Sn (5) coolants via the 'iTypeCool' input. As discussed earlier, only coolant options 1, 3, and 4 are working properly at this time and thus only those coolant options appear in Table 3.30.

Table 3.30. Test Problem Compositions to Verify iTypeFuel and iTypeCool Inputs

		Zr-alloyed fuel Sodium coolant	Oxide fuel Pb coolant	Oxide fuel Pb-Bi coolant	Nitride fuel Sodium coolant	Al Alloyed fuel Sodium coolant
Fuel Zone	N14				1.2000E-02	
	O16		1.4040E-02	1.4040E-02		
	Na23	1.1000E-02			1.1000E-02	1.1000E-02
	Al27					1.2000E-02
	Zr90	1.0800E-03				
	Pb208		1.1000E-02	5.5000E-03		
	Bi209			5.5000E-03		
	Fe56	1.8000E-02	1.8000E-02	1.8000E-02	1.8000E-02	1.8000E-02
	Pu239	1.5000E-03	1.5000E-03	1.5000E-03	1.5000E-03	1.5000E-03
	U235	1.2000E-04	1.2000E-04	1.2000E-04	1.2000E-04	1.2000E-04
	U238	5.4000E-03	5.4000E-03	5.4000E-03	5.4000E-03	5.4000E-03
Reflector Zone	Na23	5.0000E-03			5.0000E-03	5.0000E-03
	Pb208		5.0000E-03	2.5000E-03		
	Bi209			2.5000E-03		
	Fe56	7.0000E-02	7.0000E-02	7.0000E-02	7.0000E-02	7.0000E-02
Blanket Zone	Na23	7.0000E-03			7.0000E-03	7.0000E-03
	Pb208		7.0000E-03	3.5000E-03		
	Bi209			3.5000E-03		
	Fe56	1.7000E-02	1.7000E-02	1.7000E-02	1.7000E-02	1.7000E-02
	U235	1.0700E-04	1.0700E-04	1.0700E-04	1.0700E-04	1.0700E-04
	U238	1.5000E-02	1.5000E-02	1.5000E-02	1.5000E-02	1.5000E-02

For brevity, only the PMATRX based input path to VARPOW is tested here noting that the the ISOTXS input path was verified for the case using oxide fuel and sodium coolant. In addition, for the same geometry and spatial input settings to DIF3D-VARIANT, the 'VariantMonoExponents' file will be the same for all fuel and coolant types and thus does not need to be checked again. Finally, as shown earlier, the monomial basis results are a simple manipulation of the polynomial basis results and thus only the polynomial basis results (iOutput=P or T) are checked here. Table 3.31 provides the maximum relative difference calculated with the duplicate program for all of the test cases outlined by Table 3.30. As can be seen, the errors are order 10^{-7} which is consistent with the results in Table 3.29 and with the truncation error for the input provided to the duplicate code.

Table 3.31. Maximum Relative Difference Results for Different Compositions

(iTypeFuel) Fuel	(iTypeCool) Coolant	iOutput	Maximum relative difference	
			Output.VARPOW	MaterialPower.out
(1) Zr-alloyed	(1) Na	P	4.19541E-07	1.57001E-07
		T	4.29604E-07	
(2) Oxide	(3) Pb	P	1.50657E-07	1.51331E-07
		T	1.51331E-07	
	(4) Pb-Bi	P	1.50832E-07	1.51383E-07
		T	1.51383E-07	
(3) Nitride	(1) Na	P	5.21744E-07	1.55078E-07
		T	5.16188E-07	
(4) Aluminum Alloyed	(1) Na	P	6.68591E-07	1.07546E-07
		T	6.78363E-07	

It should be noted that a low order spatial approximation was used in DIF3D-VARIANT for all of these calculations (2^{nd} order) yielding just six moments as was seen in the preceding hand calculation. As will be shown later, for more complicated problems with larger spatial approximations, the magnitude of some polynomial (or monomial terms) can be very small and the reported error can be artificially large.

3.2 *VARPOW Verification on* Larger Problems

In this section, the larger and more complex problems in Table 3.32 are used to further verify VARPOW. Note that the verification test benchmark number is identified for each case. It should be noted that none of the equations covered in this report that are used by VARPOW depend upon the geometry type (i.e. Cartesian or hexagonal, two- or three-dimesional), except for the $\hat{F}$ matrix itself which is not checked for the remainder of this document. These problems, however, are more representative of typical usage of VARPOW and they can therefore ensure that implementation errors are not hidden by the preceding simple benchmark tests. All of these three benchmark cases have Zr-alloyed fuel and sodium coolant compositions.

Table 3.32. Complex Verification Test Problem Descriptions

	Case 1 (bench #12)	Case 2 (bench #16)	Case 3 (bench #13)
Geometry type	Cartesian Quarter Core Symmetry	Hexagonal Full Core	Hexagonal 1/6th Core Periodicity
# of dimensions	2	3	3
# of axial (z) mesh	1	20	29
# of radial (x-y) mesh	324	271	79
# neutron group	33	33	9
# gamma group	21	21	21
# of compositions	6	6	666
# of isotopes in ISOTXS	193	193	334
# of isotopes in PMATRX	193	193	229
# of spatial moments	28	84	84

For these three benchmark cases, the duplicate program discussed in Section 3.1.1 is again used to calculate the results in the Output.VARPOW and MaterialPower.out files and compared against those generated by VARPOW. Besides the PrintTables outputs of PMATRX, NHFLUX, and GHFLUX, additional input to define the compositions and their assignment to meshes was constructed. The isotopes categorization also needs to be specified in the input file for the duplicate program.

3.2.1 Verification of the AssignIsotope.inp Input File

As seen in Table 3.32, all three benchmark cases have lots of isotopes involved for which the optional input file 'AssignIsotope.inp' is recommened. This section will thus verify the impact of the AssignIsotope.inp file on the isotope categorization. Case 1 and 2 use the same ISOTXS and PMATRX files and they contain fresh fuel. To generate the data in the ISOTXS file, MC^2-3 [9] was used and the broad group library results change because of the composition and neutron spectrum differences that result.

Before analyzing the results from using the 'AssignIsotope.inp' file, some details on how the AssignIsotope.inp file works are needed. The isotope name U235_7 is the MC^2-3 isotope library name for the ENDF/B-VII.0 evaluation of the U-235 isotope. In the broad group ISOTXS library that MC^2-3 creates, this isotope has region-wise specifications of A0029, B0029, and C0029 referred to as ISOTXS alias names for U235_7. The AssignIsotope.inp file allows the user to categorize the isotopes by the ISOTXS alias names or the originating MC^2-3 library name. For complicated composition setups, it is typically more convenient to categorize the isotopes by the MC^2-3 library name as it requires less input. The 'AssignIsotope.inp' file used for Case 1 and 2 is shown in Figure 3-12.

```
COOLANT  NA23_7
FUEL     U234_7 U235_7 U236_7 U238_7 NP2377
FUEL     PU2387 PU2397 PU2407 PU2417 PU2427
FUEL     AM2417 AM42M7 AM2427 AM2437
FUEL     CM2427 CM2437 CM2447 CM2457 CM2467
FUEL     MO92_7 MO94_7 MO95_7 MO96_7 MO97_7 MO98_7 MO1007
FUEL     ZR90_7 ZR91_7 ZR92_7 ZR94_7 ZR96_7
FUEL     B10__7 B11__7 C____7
CLAD     CR50_7 CR52_7 CR53_7 CR54_7
CLAD     NI58_7 NI60_7 NI61_7 NI62_7 NI64_7
CLAD     FE54_7 FE56_7 FE57_7 FE58_7 MN55_7
```

Figure 3-12. AssignIsotope.inp file for Benchmark Case 1 & 2

In the regular VARPOW output, it provides the isotope categorization that will be used, an example excerpt of which is shown in Figure 3-13. With the 49 MC^2-3 library isotope names input from AssingnIsotope.inp in Figure 3-12, all 193 isotopes in the ISOTXS file are categorized as was intended. An excerpt of the default isotope categorization built into VARPOW is shown in Figure 3-14. Comparing the output in Figure 3-14 to that of Figure 3-13 one finds that the differences are that the default VARPOW approach identifies MO97_7, MO98_7, and MO1007 as part of the structural material instead of the fuel material. Because isotopes of Mo are common fission products and they are a common component of structural materials like stainless steel, one can understand the need for a user defined categorization option to make the correct decision. For the current study, the VARPOW results using the AssignIsotope.inp in Figure 3-12 are verified.

```
[VARPOW]...Expecting the GAMSOR input setup
[VARPOW]...iTypeFuel =      1
[VARPOW]...iTypeCool =      1
[VARPOW]...iOutput (0,1,2,3)=(M,S,P,T) =      3
[NDXSRF]...AssignIsotope.inp                    file was present and will attempt to import the information
[NDXSRF]...    49 inputs were read and     49 matched leading to    193 isotope settings
[VARPOW]...The following isotopes are considered fuel      isotopes   103
[VARPOW]...A0014   =MO92_7  A0015   =MO94_7  A0016   =MO95_7  A0017   =MO96_7  A0018   =MO97_7  A0019   =MO98_7  A0020   =MO1007
[VARPOW]...A0022   =ZR90_7  A0023   =ZR91_7  A0024   =ZR92_7  A0025   =ZR94_7  A0026   =ZR96_7  A0028   =U234_7  A0029   =U235_7
[VARPOW]...A0030   =U236_7  A0031   =U238_7  A0032   =NP2377  A0033   =PU2387  A0034   =PU2397  A0035   =PU2407  A0036   =PU2417
[VARPOW]...A0037   =PU2427  A0038   =AM2417  A0039   =AM42M7  A0040   =AM2427  A0041   =AM2437  A0042   =CM2427  A0043   =CM2437
[VARPOW]...A0044   =CM2447  A0045   =CM2457  A0046   =CM2467  B0014   =MO92_7  B0015   =MO94_7  B0016   =MO95_7  B0017   =MO96_7
[VARPOW]...B0018   =MO97_7  B0019   =MO98_7  B0020   =MO1007  B0022   =ZR90_7  B0023   =ZR91_7  B0024   =ZR92_7  B0025   =ZR94_7
[VARPOW]...B0026   =ZR96_7  B0028   =U234_7  B0029   =U235_7  B0030   =U236_7  B0031   =U238_7  B0032   =NP2377  B0033   =PU2387
[VARPOW]...B0034   =PU2397  B0035   =PU2407  B0036   =PU2417  B0037   =PU2427  B0038   =AM2417  B0039   =AM42M7  B0040   =AM2427
[VARPOW]...B0041   =AM2437  B0042   =CM2427  B0043   =CM2437  B0044   =CM2447  B0045   =CM2457  B0046   =CM2467  C0014   =MO92_7
[VARPOW]...C0015   =MO94_7  C0016   =MO95_7  C0017   =MO96_7  C0018   =MO97_7  C0019   =MO98_7  C0020   =MO1007  C0022   =ZR90_7
[VARPOW]...C0023   =ZR91_7  C0024   =ZR92_7  C0025   =ZR94_7  C0026   =ZR96_7  C0029   =U235_7  C0031   =U238_7  D0014   =MO92_7
[VARPOW]...D0015   =MO94_7  D0016   =MO95_7  D0017   =MO96_7  D0018   =MO97_7  D0019   =MO98_7  D0020   =MO1007  E0014   =MO92_7
[VARPOW]...E0015   =MO94_7  E0016   =MO95_7  E0017   =MO96_7  E0018   =MO97_7  E0019   =MO98_7  E0020   =MO1007  E0047   =B10__7
[VARPOW]...E0048   =B11__7  E0049   =C____7  F0014   =MO92_7  F0015   =MO94_7  F0016   =MO95_7  F0017   =MO96_7  F0018   =MO97_7
[VARPOW]...F0019   =MO98_7  F0020   =MO1007  F0047   =B10__7  F0048   =B11__7  F0049   =C____7
[VARPOW]...The following isotopes are considered structure isotopes    84
[VARPOW]...A0001   =CR50_7  A0002   =CR52_7  A0003   =CR53_7  A0004   =CR54_7  A0005   =NI58_7  A0006   =NI60_7  A0007   =NI61_7
[VARPOW]...A0008   =NI62_7  A0009   =NI64_7  A0010   =FE54_7  A0011   =FE56_7  A0012   =FE57_7  A0013   =FE58_7  A0021   =MN55_7
[VARPOW]...B0001   =CR50_7  B0002   =CR52_7  B0003   =CR53_7  B0004   =CR54_7  B0005   =NI58_7  B0006   =NI60_7  B0007   =NI61_7
[VARPOW]...B0008   =NI62_7  B0009   =NI64_7  B0010   =FE54_7  B0011   =FE56_7  B0012   =FE57_7  B0013   =FE58_7  B0021   =MN55_7
[VARPOW]...C0001   =CR50_7  C0002   =CR52_7  C0003   =CR53_7  C0004   =CR54_7  C0005   =NI58_7  C0006   =NI60_7  C0007   =NI61_7
[VARPOW]...C0008   =NI62_7  C0009   =NI64_7  C0010   =FE54_7  C0011   =FE56_7  C0012   =FE57_7  C0013   =FE58_7  C0021   =MN55_7
[VARPOW]...D0001   =CR50_7  D0002   =CR52_7  D0003   =CR53_7  D0004   =CR54_7  D0005   =NI58_7  D0006   =NI60_7  D0007   =NI61_7
[VARPOW]...D0008   =NI62_7  D0009   =NI64_7  D0010   =FE54_7  D0011   =FE56_7  D0012   =FE57_7  D0013   =FE58_7  D0021   =MN55_7
[VARPOW]...E0001   =CR50_7  E0002   =CR52_7  E0003   =CR53_7  E0004   =CR54_7  E0005   =NI58_7  E0006   =NI60_7  E0007   =NI61_7
[VARPOW]...E0008   =NI62_7  E0009   =NI64_7  E0010   =FE54_7  E0011   =FE56_7  E0012   =FE57_7  E0013   =FE58_7  E0021   =MN55_7
[VARPOW]...F0001   =CR50_7  F0002   =CR52_7  F0003   =CR53_7  F0004   =CR54_7  F0005   =NI58_7  F0006   =NI60_7  F0007   =NI61_7
[VARPOW]...F0008   =NI62_7  F0009   =NI64_7  F0010   =FE54_7  F0011   =FE56_7  F0012   =FE57_7  F0013   =FE58_7  F0021   =MN55_7
[VARPOW]...
[VARPOW]...The following isotopes are considered coolant   isotopes     6
[VARPOW]...A0027   =NA23_7  B0027   =NA23_7  C0027   =NA23_7  D0027   =NA23_7  E0027   =NA23_7  F0027   =NA23_7
```

Figure 3-13. Case 1&2 VARPOW Screen Output with a Provided AssignIsotope.inp File

```
[VARPOW]...Expecting the GAMSOR input setup
[VARPOW]...iTypeFuel =      1
[VARPOW]...iTypeCool =      1
[VARPOW]...iOutput (0,1,2,3)=(M,S,P,T) =      3
[NDXSRF]...AssignIsotope.inp                        file was not present.
[VARPOW]...The following isotopes are considered fuel      isotopes    85
[VARPOW]...A0014   =MO92_7  A0015   =MO94_7  A0016   =MO95_7  A0017   =MO96_7  A0022   =ZR90_7  A0023   =ZR91_7  A0024   =ZR92_7
[VARPOW]...A0025   =ZR94_7  A0026   =ZR96_7  A0028   =U234_7  A0029   =U235_7  A0030   =U236_7  A0031   =U238_7  A0032   =NP2377
[VARPOW]...A0033   =PU2387  A0034   =PU2397  A0035   =PU2407  A0036   =PU2417  A0037   =PU2427  A0038   =AM2417  A0039   =AM42M7
[VARPOW]...A0040   =AM2427  A0041   =AM2437  A0042   =CM2427  A0043   =CM2437  A0044   =CM2447  A0045   =CM2457  A0046   =CM2467
[VARPOW]...B0014   =MO92_7  B0015   =MO94_7  B0016   =MO95_7  B0017   =MO96_7  B0022   =ZR90_7  B0023   =ZR91_7  B0024   =ZR92_7
[VARPOW]...B0025   =ZR94_7  B0026   =ZR96_7  B0028   =U234_7  B0029   =U235_7  B0030   =U236_7  B0031   =U238_7  B0032   =NP2377
[VARPOW]...B0033   =PU2387  B0034   =PU2397  B0035   =PU2407  B0036   =PU2417  B0037   =PU2427  B0038   =AM2417  B0039   =AM42M7
[VARPOW]...B0040   =AM2427  B0041   =AM2437  B0042   =CM2427  B0043   =CM2437  B0044   =CM2447  B0045   =CM2457  B0046   =CM2467
[VARPOW]...C0014   =MO92_7  C0015   =MO94_7  C0016   =MO95_7  C0017   =MO96_7  C0022   =ZR90_7  C0023   =ZR91_7  C0024   =ZR92_7
[VARPOW]...C0025   =ZR94_7  C0026   =ZR96_7  C0029   =U235_7  C0031   =U238_7  D0014   =MO92_7  D0015   =MO94_7  D0016   =MO95_7
[VARPOW]...D0017   =MO96_7  E0014   =MO92_7  E0015   =MO94_7  E0016   =MO95_7  E0017   =MO96_7  E0047   =B10__7  E0048   =B11__7
[VARPOW]...E0049   =C____7  F0014   =MO92_7  F0015   =MO94_7  F0016   =MO95_7  F0017   =MO96_7  F0047   =B10__7  F0048   =B11__7
[VARPOW]...F0049   =C____7
[VARPOW]...The following isotopes are considered structure isotopes   102
[VARPOW]...A0001   =CR50_7  A0002   =CR52_7  A0003   =CR53_7  A0004   =CR54_7  A0005   =NI58_7  A0006   =NI60_7  A0007   =NI61_7
[VARPOW]...A0008   =NI62_7  A0009   =NI64_7  A0010   =FE54_7  A0011   =FE56_7  A0012   =FE57_7  A0013   =FE58_7  A0018   =MO97_7
[VARPOW]...A0019   =MO98_7  A0020   =MO1007  A0021   =MN55_7  B0001   =CR50_7  B0002   =CR52_7  B0003   =CR53_7  B0004   =CR54_7
[VARPOW]...B0005   =NI58_7  B0006   =NI60_7  B0007   =NI61_7  B0008   =NI62_7  B0009   =NI64_7  B0010   =FE54_7  B0011   =FE56_7
[VARPOW]...B0012   =FE57_7  B0013   =FE58_7  B0018   =MO97_7  B0019   =MO98_7  B0020   =MO1007  B0021   =MN55_7  C0001   =CR50_7
[VARPOW]...C0002   =CR52_7  C0003   =CR53_7  C0004   =CR54_7  C0005   =NI58_7  C0006   =NI60_7  C0007   =NI61_7  C0008   =NI62_7
[VARPOW]...C0009   =NI64_7  C0010   =FE54_7  C0011   =FE56_7  C0012   =FE57_7  C0013   =FE58_7  C0018   =MO97_7  C0019   =MO98_7
[VARPOW]...C0020   =MO1007  C0021   =MN55_7  D0001   =CR50_7  D0002   =CR52_7  D0003   =CR53_7  D0004   =CR54_7  D0005   =NI58_7
[VARPOW]...D0006   =NI60_7  D0007   =NI61_7  D0008   =NI62_7  D0009   =NI64_7  D0010   =FE54_7  D0011   =FE56_7  D0012   =FE57_7
[VARPOW]...D0013   =FE58_7  D0018   =MO97_7  D0019   =MO98_7  D0020   =MO1007  D0021   =MN55_7  E0001   =CR50_7  E0002   =CR52_7
[VARPOW]...E0003   =CR53_7  E0004   =CR54_7  E0005   =NI58_7  E0006   =NI60_7  E0007   =NI61_7  E0008   =NI62_7  E0009   =NI64_7
[VARPOW]...E0010   =FE54_7  E0011   =FE56_7  E0012   =FE57_7  E0013   =FE58_7  E0018   =MO97_7  E0019   =MO98_7  E0020   =MO1007
[VARPOW]...E0021   =MN55_7  F0001   =CR50_7  F0002   =CR52_7  F0003   =CR53_7  F0004   =CR54_7  F0005   =NI58_7  F0006   =NI60_7
[VARPOW]...F0007   =NI61_7  F0008   =NI62_7  F0009   =NI64_7  F0010   =FE54_7  F0011   =FE56_7  F0012   =FE57_7  F0013   =FE58_7
[VARPOW]...F0018   =MO97_7  F0019   =MO98_7  F0020   =MO1007  F0021   =MN55_7
[VARPOW]...The following isotopes are considered coolant   isotopes     6
[VARPOW]...A0027   =NA23_7  B0027   =NA23_7  C0027   =NA23_7  D0027   =NA23_7  E0027   =NA23_7  F0027   =NA23_7
```

Figure 3-14. Case 1&2 VARPOW Screen Output without a Provided AssignIsotope.inp File

Case 3 uses a cross section data set generated using ENDF/B-V data and it has depleted fuel with lumped fission products. The AssignIsotope.inp file tested has a mixed usage of MC^2-3 library names and ISOTXS alias names as shown in Figure 3-15. The isotopes FP35, FP38, FP39, FP40, and FP41 are part of the lumped fission products from U-235, U-238, Pu-239, Pu-240, and Pu-241, respectively. They do not have corresponding MC^2-3 name and thus the ISOTXS alias names are used. It should be pointed out that 'NA23 S' is the older approach to defining the ISOTXS alias names and MC^2-3 isotope names. Today the space is replaced with a '_' to facilitate free format reading of the user input. The GNIP4C part of DIF3D will alter the ISOTXS alias names such as 'NA23 A' into 'NA23A' but this approach is not taken in VARPOW. Thus VARPOW will interpret the displayed input as two isotopes with names NA23 and S. Neither of these will match the isotopes in the ISOTXS file and VARPOW will report how many inputs matched and did not match as seen in Figure 3-16. This is of course not a problem so much as it indicates that the default algorithm will be used to categorize those isotopes. Thus this test case checks all possible input options of AssignIsotope.inp.

```
COOLANT  NA23 S
FUEL     LFP35  LFP38  LFP39  LFP40  LFP41
FUEL     NP237V AM243V ZR  SV AM242M PU239V
FUEL     LFPMO2 CM2415 CM2425 AL27 5 XE1355
FUEL     K    5 MO   S N-14 5 O-16 5 PU2405
FUEL     PU2415 B-10 5 C    5 U-2355 B-11 5
FUEL     HE4  5 TH2325 U-2335 U-2375 NP2385
FUEL     PU2365 PU2375 PU2435 PU2445 AM2425
FUEL     PU2385 PU2425 CM2435 CM2445 CM2465
FUEL     AM2415 PA2335 U-2345 U-2365 SM1495
FUEL     U-2385 U3FP13 U5FP13 P9FP13 U3FP23
FUEL     U5FP23 P9FP23 HOMOG  NP237V PU239V
FUEL     HYDRGN TA1815 NB93 5 FP35   RE35
FUEL     FP38   RE38   FP39   RE39   FP40
FUEL     RE40   FP41   RE41
CLAD     FE  SV CR   S NI   S MN55 S
```

Figure 3-15. AssignIsotope.inp File for Case 3

The VARPOW output excerpts showing the categorization of isotopes for this test case, with and without using the AssignIsotope.inp file are shown in Figure 3-16 and Figure 3-17, respectively. Inspection of the differences in the isotope categorization shows that without the AssignIsotope.inp file the lumped fission products RE35, RE38, RE39, RE40 and RE41 are mistakenly identified as part of the structural material instead of the fuel material.

Looking at the output in Figure 3-16, there are several error messages returned from the NDXSRF module which is responsible for reading the AssignIsotope.inp file. These error messages occur because the free format reader identifies the isolated "5" values in Figure 3-15 as numbers rather than characters. From Figure 3-16, the free format reading of Figure 3-15 identified 89 isotope names from the input where the intention was only 73 and thus 16 of those inputs were identified as 32 inputs. The output from VARPOW in Figure 3-16 indicates that 59 isotope names provided by the user matched but a count of the valid names leads to 73-16 = 57. As it turns out, the ISOTXS alias names AL27 and K are used and thus the 'K 5' and 'AL27 5' inputs in Figure 3-15 are accidentally identified correctly as ISOTXS isotopes AL27 and K instead of the intended MC^2 library names. For the current study, the VARPOW results using the AssignIsotope.inp file in Figure 3-15 are verified.

```
[NDXSRF]...AssignIsotope.inp                          file was present and will attempt to import the information
[NDXSRF]...Unknown keyword, check input for line      4
[NDXSRF]...Unknown keyword, check input for line      5
[NDXSRF]...Unknown keyword, check input for line      6
[NDXSRF]...Unknown keyword, check input for line      7
[NDXSRF]...Unknown keyword, check input for line     13
[NDXSRF]...Some errors were detected as listed above.
[NDXSRF]...    89 inputs were read and     59 matched leading to    251 isotope settings
[VARPOW]...The following isotopes are considered fuel      isotopes   289
[VARPOW]...LFP35   =LFP35   LFP38   =LFP38   LFP39   =LFP39   LFP40   =LFP40   LFP41   =LFP41   N237X   =NP237V  N237I   =NP237V
[VARPOW]...N237M   =NP237V  N237Z   =NP237V  N237O   =NP237V  N237B   =NP237V  A243X   =AM243V  A243I   =AM243V  A243Y   =AM243V
[VARPOW]...A243M   =AM243V  A243Z   =AM243V  A243O   =AM243V  A243B   =AM243V  ZIRCX   =ZR  SV  ZIRCI   =ZR  SV  ZIRCY   =ZR  SV
[VARPOW]...ZIRCM   =ZR  SV  ZIRCZ   =ZR  SV  ZIRCO   =ZR  SV  ZIRCB   =ZR  SV  ZIRCR   =ZR  SV  A24MX   =AM242M  A24MI   =AM242M
[VARPOW]...A24MY   =AM242M  A24MM   =AM242M  A24MZ   =AM242M  A24MO   =AM242M  A24MB   =AM242M  P239X   =PU239V  P239I   =PU239V
[VARPOW]...P239M   =PU239V  P239Z   =PU239V  P239O   =PU239V  P239B   =PU239V  LFPPX   =LFPMO2  LFPPI   =LFPMO2  LFPPY   =LFPMO2
[VARPOW]...LFPPM   =LFPMO2  LFPPZ   =LFPMO2  LFPPO   =LFPMO2  LFPPB   =LFPMO2  C241X   =CM2415  C241I   =CM2415  C241Y   =CM2415
[VARPOW]...C241M   =CM2415  C241Z   =CM2415  C241O   =CM2415  C241B   =CM2415  C242X   =CM2425  C242I   =CM2425  C242Y   =CM2425
[VARPOW]...C242M   =CM2425  C242Z   =CM2425  C242O   =CM2425  C242B   =CM2425  AL27    =AL27 5  X135    =XE1355  K       =K    5
[VARPOW]...MOX     =MO   S  MOI     =MO   S  MOY     =MO   S  MOM     =MO   S  MOZ     =MO   S  MOO     =MO   S  MOB     =MO   S
[VARPOW]...MOR     =MO   S  MOS     =MO   S  N-14I   =N-14 5  N-14M   =N-14 5  N-14O   =N-14 5  N-14B   =N-14 5  O-16X   =O-16 5
[VARPOW]...O-16I   =O-16 5  O-16Y   =O-16 5  O-16M   =O-16 5  O-16Z   =O-16 5  O-16O   =O-16 5  O-16B   =O-16 5  P240X   =PU2405
[VARPOW]...P240I   =PU2405  P240Y   =PU2405  P240M   =PU2405  P240Z   =PU2405  P240O   =PU2405  P240B   =PU2405  P241X   =PU2415
[VARPOW]...P241I   =PU2415  P241Y   =PU2415  P241M   =PU2415  P241Z   =PU2415  P241O   =PU2415  P241B   =PU2415  B-10I   =B-10 5
[VARPOW]...B-10M   =B-10 5  B-10O   =B-10 5  B-10S   =B-10 5  C-12I   =C    5  C-12M   =C    5  C-12O   =C    5  C-12S   =C    5
[VARPOW]...U235X   =U-2355  U235I   =U-2355  U235Y   =U-2355  U235M   =U-2355  U235Z   =U-2355  U235O   =U-2355  U235B   =U-2355
[VARPOW]...B-11I   =B-11 5  B-11M   =B-11 5  B-11O   =B-11 5  B-11S   =B-11 5  HE-4    =HE4  5  T232X   =TH2325  T232I   =TH2325
[VARPOW]...T232Y   =TH2325  T232M   =TH2325  T232Z   =TH2325  T232O   =TH2325  T232B   =TH2325  U233X   =U-2335  U233I   =U-2335
[VARPOW]...U233Y   =U-2335  U233M   =U-2335  U233Z   =U-2335  U233O   =U-2335  U233B   =U-2335  U237X   =U-2375  U237I   =U-2375
[VARPOW]...U237Y   =U-2375  U237M   =U-2375  U237Z   =U-2375  U237O   =U-2375  U237B   =U-2375  N238X   =NP2385  N238I   =NP2385
[VARPOW]...N238Y   =NP2385  N238M   =NP2385  N238Z   =NP2385  N238O   =NP2385  N238B   =NP2385  P236X   =PU2365  P236I   =PU2365
[VARPOW]...P236Y   =PU2365  P236M   =PU2365  P236Z   =PU2365  P236O   =PU2365  P236B   =PU2365  P237X   =PU2375  P237I   =PU2375
[VARPOW]...P237Y   =PU2375  P237M   =PU2375  P237Z   =PU2375  P237O   =PU2375  P237B   =PU2375  P243X   =PU2435  P243I   =PU2435
[VARPOW]...P243Y   =PU2435  P243M   =PU2435  P243Z   =PU2435  P243O   =PU2435  P243B   =PU2435  P244X   =PU2445  P244I   =PU2445
[VARPOW]...P244Y   =PU2445  P244M   =PU2445  P244Z   =PU2445  P244O   =PU2445  P244B   =PU2445  A242X   =AM2425  A242I   =AM2425
[VARPOW]...A242Y   =AM2425  A242M   =AM2425  A242Z   =AM2425  A242O   =AM2425  A242B   =AM2425  P238X   =PU2385  P238I   =PU2385
[VARPOW]...P238Y   =PU2385  P238M   =PU2385  P238Z   =PU2385  P238O   =PU2385  P238B   =PU2385  P242X   =PU2425  P242I   =PU2425
[VARPOW]...P242Y   =PU2425  P242M   =PU2425  P242Z   =PU2425  P242O   =PU2425  P242B   =PU2425  C243X   =CM2435  C243I   =CM2435
[VARPOW]...C243Y   =CM2435  C243M   =CM2435  C243Z   =CM2435  C243O   =CM2435  C243B   =CM2435  C244X   =CM2445  C244I   =CM2445
[VARPOW]...C244Y   =CM2445  C244M   =CM2445  C244Z   =CM2445  C244O   =CM2445  C244B   =CM2445  C245X   =CM2455  C245I   =CM2455
[VARPOW]...C245Y   =CM2455  C245M   =CM2455  C245Z   =CM2455  C245O   =CM2455  C245B   =CM2455  C246X   =CM2465  C246I   =CM2465
[VARPOW]...C246Y   =CM2465  C246M   =CM2465  C246Z   =CM2465  C246O   =CM2465  C246B   =CM2465  A241X   =AM2415  A241I   =AM2415
[VARPOW]...A241Y   =AM2415  A241M   =AM2415  A241Z   =AM2415  A241O   =AM2415  A241B   =AM2415  P233X   =PA2335  P233I   =PA2335
[VARPOW]...P233Y   =PA2335  P233M   =PA2335  P233Z   =PA2335  P233O   =PA2335  P233B   =PA2335  U234X   =U-2345  U234I   =U-2345
[VARPOW]...U234Y   =U-2345  U234M   =U-2345  U234Z   =U-2345  U234O   =U-2345  U234B   =U-2345  U236X   =U-2365  U236I   =U-2365
[VARPOW]...U236Y   =U-2365  U236M   =U-2365  U236Z   =U-2365  U236O   =U-2365  U236B   =U-2365  S149    =SM1495  U238X   =U-2385
[VARPOW]...U238I   =U-2385  U238Y   =U-2385  U238M   =U-2385  U238Z   =U-2385  U238O   =U-2385  U238B   =U-2385  U313    =U3FP13
[VARPOW]...U513    =U5FP13  P913    =P9FP13  U323    =U3FP23  U333    =U3FP33  U523    =U5FP23  U533    =U5FP33  P923    =P9FP23
[VARPOW]...P933    =P9FP33  LFPP3   =HOMOG   LFPP5   =HOMOG   LFPP9   =HOMOG   DUMP1   =HOMOG   N237Y   =NP237V  P239Y   =PU239V
[VARPOW]...HYDRGN  =HYDRGN  DUMP2   =HOMOG   DUMP3   =HOMOG   DUMP4   =HOMOG   TA      =TA1815  NB      =NB93 5  FP35    =FP35
[VARPOW]...RE35    =RE35    FP38    =FP38    RE38    =RE38    FP39    =FP39    RE39    =RE39    FP40    =FP40    RE40    =RE40
[VARPOW]...FP41    =FP41    RE41    =RE41
[VARPOW]...The following isotopes are considered structure isotopes    36
[VARPOW]...FEX     =FE  SV  FEI     =FE  SV  FEY     =FE  SV  FEM     =FE  SV  FEZ     =FE  SV  FEO     =FE  SV  FEB     =FE  SV
[VARPOW]...FER     =FE  SV  FES     =FE  SV  CRX     =CR   S  CRI     =CR   S  CRY     =CR   S  CRM     =CR   S  CRZ     =CR   S
[VARPOW]...CRO     =CR   S  CRB     =CR   S  CRR     =CR   S  CRS     =CR   S  NIX     =NI   S  NII     =NI   S  NIY     =NI   S
[VARPOW]...NIM     =NI   S  NIZ     =NI   S  NIO     =NI   S  NIB     =NI   S  NIR     =NI   S  NIS     =NI   S  MN55X   =MN55 S
[VARPOW]...MN55I   =MN55 S  MN55Y   =MN55 S  MN55M   =MN55 S  MN55Z   =MN55 S  MN55O   =MN55 S  MN55B   =MN55 S  MN55R   =MN55 S
[VARPOW]...MN55S   =MN55 S
[VARPOW]...The following isotopes are considered coolant   isotopes     9
[VARPOW]...NA23X   =NA23 S  NA23I   =NA23 S  NA23Y   =NA23 S  NA23M   =NA23 S  NA23Z   =NA23 S  NA23O   =NA23 S  NA23B   =NA23 S
[VARPOW]...NA23R   =NA23 S  NA23S   =NA23 S
```

Figure 3-16. Case 3 VARPOW Screen Output with a Provided AssignIsotope.inp File

```
[NDXSRF]...AssignIsotope.inp                    file was not present.
[VARPOW]...The following isotopes are considered fuel      isotopes   284
[VARPOW]...LFP35   =LFP35   LFP38   =LFP38   LFP39   =LFP39   LFP40   =LFP40   LFP41   =LFP41   N237X   =NP237V  N237I   =NP237V
[VARPOW]...N237M   =NP237V  N237Z   =NP237V  N237O   =NP237V  N237B   =NP237V  A243X   =AM243V  A243I   =AM243V  A243Y   =AM243V
[VARPOW]...A243M   =AM243V  A243Z   =AM243V  A243O   =AM243V  A243B   =AM243V  ZIRCX   =ZR  SV  ZIRCI   =ZR  SV  ZIRCY   =ZR  SV
[VARPOW]...ZIRCM   =ZR  SV  ZIRCZ   =ZR  SV  ZIRCO   =ZR  SV  ZIRCB   =ZR  SV  ZIRCR   =ZR  SV  A24MX   =AM242M  A24MI   =AM242M
[VARPOW]...A24MY   =AM242M  A24MM   =AM242M  A24MZ   =AM242M  A24MO   =AM242M  A24MB   =AM242M  P239X   =PU239V  P239I   =PU239V
[VARPOW]...P239M   =PU239V  P239Z   =PU239V  P239O   =PU239V  P239B   =PU239V  LFPPX   =LFPMO2  LFPPI   =LFPMO2  LFPPY   =LFPMO2
[VARPOW]...LFPPM   =LFPMO2  LFPPZ   =LFPMO2  LFPPO   =LFPMO2  LFPPB   =LFPMO2  C241X   =CM2415  C241I   =CM2415  C241Y   =CM2415
[VARPOW]...C241M   =CM2415  C241Z   =CM2415  C241O   =CM2415  C241B   =CM2415  C242X   =CM2425  C242I   =CM2425  C242Y   =CM2425
[VARPOW]...C242M   =CM2425  C242Z   =CM2425  C242O   =CM2425  C242B   =CM2425  AL27    =AL27 5  X135    =XE1355  K       =K    5
[VARPOW]...MOX     =MO    S  MOI     =MO    S  MOY     =MO    S  MOM     =MO    S  MOZ     =MO    S  MOO     =MO    S  MOB     =MO    S
[VARPOW]...MOR     =MO    S  MOS     =MO    S  N-14I   =N-14 5  N-14M   =N-14 5  N-14O   =N-14 5  N-14B   =N-14 5  O-16X   =O-16 5
[VARPOW]...O-16I   =O-16 5  O-16Y   =O-16 5  O-16M   =O-16 5  O-16Z   =O-16 5  O-16O   =O-16 5  O-16B   =O-16 5  P240X   =PU2405
[VARPOW]...P240I   =PU2405  P240Y   =PU2405  P240M   =PU2405  P240Z   =PU2405  P240O   =PU2405  P240B   =PU2405  P241X   =PU2415
[VARPOW]...P241I   =PU2415  P241Y   =PU2415  P241M   =PU2415  P241Z   =PU2415  P241O   =PU2415  P241B   =PU2415  B-10I   =B-10 5
[VARPOW]...B-10M   =B-10 5  B-10O   =B-10 5  B-10S   =B-10 5  C-12I   =C    5  C-12M   =C    5  C-12O   =C    5  C-12S   =C    5
[VARPOW]...U235X   =U-2355  U235I   =U-2355  U235Y   =U-2355  U235M   =U-2355  U235Z   =U-2355  U235O   =U-2355  U235B   =U-2355
[VARPOW]...B-11I   =B-11 5  B-11M   =B-11 5  B-11O   =B-11 5  B-11S   =B-11 5  HE-4    =HE4  5  T232X   =TH2325  T232I   =TH2325
[VARPOW]...T232Y   =TH2325  T232M   =TH2325  T232Z   =TH2325  T232O   =TH2325  T232B   =TH2325  U233X   =U-2335  U233I   =U-2335
[VARPOW]...U233Y   =U-2335  U233M   =U-2335  U233Z   =U-2335  U233O   =U-2335  U233B   =U-2335  U237X   =U-2375  U237I   =U-2375
[VARPOW]...U237Y   =U-2375  U237M   =U-2375  U237Z   =U-2375  U237O   =U-2375  U237B   =U-2375  N238X   =NP2385  N238I   =NP2385
[VARPOW]...N238Y   =NP2385  N238M   =NP2385  N238Z   =NP2385  N238O   =NP2385  N238B   =NP2385  P236X   =PU2365  P236I   =PU2365
[VARPOW]...P236Y   =PU2365  P236M   =PU2365  P236Z   =PU2365  P236O   =PU2365  P236B   =PU2365  P237X   =PU2375  P237I   =PU2375
[VARPOW]...P237Y   =PU2375  P237M   =PU2375  P237Z   =PU2375  P237O   =PU2375  P237B   =PU2375  P243X   =PU2435  P243I   =PU2435
[VARPOW]...P243Y   =PU2435  P243M   =PU2435  P243Z   =PU2435  P243O   =PU2435  P243B   =PU2435  P244X   =PU2445  P244I   =PU2445
[VARPOW]...P244Y   =PU2445  P244M   =PU2445  P244Z   =PU2445  P244O   =PU2445  P244B   =PU2445  A242X   =AM2425  A242I   =AM2425
[VARPOW]...A242Y   =AM2425  A242M   =AM2425  A242Z   =AM2425  A242O   =AM2425  A242B   =AM2425  P238X   =PU2385  P238I   =PU2385
[VARPOW]...P238Y   =PU2385  P238M   =PU2385  P238Z   =PU2385  P238O   =PU2385  P238B   =PU2385  P242X   =PU2425  P242I   =PU2425
[VARPOW]...P242Y   =PU2425  P242M   =PU2425  P242Z   =PU2425  P242O   =PU2425  P242B   =PU2425  C243X   =CM2435  C243I   =CM2435
[VARPOW]...C243Y   =CM2435  C243M   =CM2435  C243Z   =CM2435  C243O   =CM2435  C243B   =CM2435  C244X   =CM2445  C244I   =CM2445
[VARPOW]...C244Y   =CM2445  C244M   =CM2445  C244Z   =CM2445  C244O   =CM2445  C244B   =CM2445  C245X   =CM2455  C245I   =CM2455
[VARPOW]...C245Y   =CM2455  C245M   =CM2455  C245Z   =CM2455  C245O   =CM2455  C245B   =CM2455  C246X   =CM2465  C246I   =CM2465
[VARPOW]...C246Y   =CM2465  C246M   =CM2465  C246Z   =CM2465  C246O   =CM2465  C246B   =CM2465  A241X   =AM2415  A241I   =AM2415
[VARPOW]...A241Y   =AM2415  A241M   =AM2415  A241Z   =AM2415  A241O   =AM2415  A241B   =AM2415  P233X   =PA2335  P233I   =PA2335
[VARPOW]...P233Y   =PA2335  P233M   =PA2335  P233Z   =PA2335  P233O   =PA2335  P233B   =PA2335  U234X   =U-2345  U234I   =U-2345
[VARPOW]...U234Y   =U-2345  U234M   =U-2345  U234Z   =U-2345  U234O   =U-2345  U234B   =U-2345  U236X   =U-2365  U236I   =U-2365
[VARPOW]...U236Y   =U-2365  U236M   =U-2365  U236Z   =U-2365  U236O   =U-2365  U236B   =U-2365  S149    =SM1495  U238X   =U-2385
[VARPOW]...U238I   =U-2385  U238Y   =U-2385  U238M   =U-2385  U238Z   =U-2385  U238O   =U-2385  U238B   =U-2385  U313    =U3FP13
[VARPOW]...U513    =U5FP13  P913    =P9FP13  U323    =U3FP23  U333    =U3FP33  U523    =U5FP23  U533    =U5FP33  P923    =P9FP23
[VARPOW]...P933    =P9FP33  LFPP3   =HOMOG   LFPP5   =HOMOG   LFPP9   =HOMOG   DUMP1   =HOMOG   N237Y   =NP237V  P239Y   =PU239V
[VARPOW]...HYDRGN  =HYDRGN  DUMP2   =HOMOG   DUMP3   =HOMOG   DUMP4   =HOMOG   TA      =TA1815  NB      =NB93 5  FP35    =FP35
[VARPOW]...FP38    =FP38    FP39    =FP39    FP40    =FP40    FP41    =FP41
[VARPOW]...The following isotopes are considered structure isotopes    41
[VARPOW]...FEX     =FE  SV  FEI     =FE  SV  FEY     =FE  SV  FEM     =FE  SV  FEZ     =FE  SV  FEO     =FE  SV  FEB     =FE  SV
[VARPOW]...FER     =FE  SV  FES     =FE  SV  CRX     =CR    S  CRI     =CR    S  CRY     =CR    S  CRM     =CR    S  CRZ     =CR    S
[VARPOW]...CRO     =CR    S  CRB     =CR    S  CRR     =CR    S  CRS     =CR    S  NIX     =NI    S  NII     =NI    S  NIY     =NI    S
[VARPOW]...NIM     =NI    S  NIZ     =NI    S  NIO     =NI    S  NIB     =NI    S  NIR     =NI    S  NIS     =NI    S  MN55X   =MN55 S
[VARPOW]...MN55I   =MN55 S  MN55Y   =MN55 S  MN55M   =MN55 S  MN55Z   =MN55 S  MN55O   =MN55 S  MN55B   =MN55 S  MN55R   =MN55 S
[VARPOW]...MN55S   =MN55 S  RE35    =RE35    RE38    =RE38    RE39    =RE39    RE40    =RE40    RE41    =RE41
[VARPOW]...The following isotopes are considered coolant   isotopes     9
[VARPOW]...NA23X   =NA23 S  NA23I   =NA23 S  NA23Y   =NA23 S  NA23M   =NA23 S  NA23Z   =NA23 S  NA23O   =NA23 S  NA23B   =NA23 S
[VARPOW]...NA23R   =NA23 S  NA23S   =NA23 S
```

Figure 3-17. Case 3 VARPOW Screen Output without a Provided AssignIsotope.inp File

3.2.2 Independent Calculation of the VARPOW Outputs

For these three benchmark cases, the VARPOW results using the described AssignIsotope.inp files are compared with the independent calculation of the duplicate program. Both ISOTXS based and PMATRX based input options for VARPOW are tested along with every iOutput option. As shown earlier in Table 3.32, these benchmark cases have a large number of values to check given the number of meshes and spatial moments. Consequently, it is not practical to display a detailed comparison as was done for the earlier Excel based hand calculation where the results for every spatial moment in every mesh were provided. Instead, only the maximum (relative) difference between the duplicate program and VARPOW is shown in Table 3.33.

Table 3.33. Maximum Relative Difference Results for Test Cases 1 - 3

Benchmark	Input	iOutput	Maximum relative difference		
			Output.VARPOW		MaterialPower.out
			for pow. den. moments	for fast flux moments	
Case 1	ISOTXS	M	1.00012E-07	5.81535E-08	8.08853E-08
		S	3.56536E-07		
		P	5.52853E-05	7.18437E-07	
		T	**5.80732E-04**		
	PMATRX	M	1.67919E-07	5.62738E-08	8.96146E-08
		S	6.16268E-06		
		P	1.21320E-04	5.42359E-07	
		T	**1.46179E-04**		
Case 2	ISOTXS	M	4.98277E-06	1.71552E-05	9.08970E-08
		S	1.47220E-05		
		P	1.66690E-04	1.38669E-05	
		T	**5.22822E-04**		
	PMATRX	M	6.45216E-05	1.71552E-05	9.76103E-08
		S	1.89386E-04		
		P	2.21191E-04	1.04658E-05	
		T	**7.15745E-04**		
Case 3	ISOTXS	M	1.71264E-05	2.33629E-05	6.75858E-08
		S	2.61995E-04		
		P	1.12841E-03	7.31218E-04	
		T	**1.40171E-03**		
		P[1)]	2.18586E-05	9.62266E-07	
		T[1)]	1.29794E-04		
		P[2)]	7.73587E-06	1.43319E-07	
		T[2)]	4.07465E-05		
	PMATRX	M	7.11180E-06	2.37686E-05	1.58085E-07
		S	9.16358E-05		
		P	1.47640E-03	1.62190E-03	
		T	**7.75165E-02**		
		P[1)]	2.90534E-04	2.72521E-06	
		T[1)]	5.23596E-04		
		P[2)]	2.90534E-04	3.75872E-07	
		T[2)]	2.91144E-05		

1) Only includes the first 10 spatial moments
2) Only includes the first 4 spatial moments

For the Output.VARPOW data, the maximum (relative) difference between the duplicate program and VARPOW, for the power density and fast neutron flux moments, are listed separately in Table 3.33. It should be noted that the VARPOW fast neutron flux (moments) should be mathematically the same between the ISOTXS and PMATRX inputs, however, the ISOTXS and PMATRX files have different stored formats, and thus precision, for the energy boundaries. The excerpts of PrintTables output (block of fast neutron flux moments) of Output.VARPOW for case 3 (iOutput=P) using the ISOTXS and PMATRX inputs are shown in Figure 3-18. One can see the minor differences between the fast neutron flux (moments) between the ISOTXS and PMATRX inputs. Because one of those energy boundaries spans the

100 keV point, the calculation of the contribution from that energy group is slightly different between the two input paths. It should be noted that for Case 3 iOutput=P, the maximum relative difference for the fast neutron flux moments using ISOTXS and PMATRX inputs are 7.31218E-04 and 1.62190E-03, respectively. This difference is expected.

```
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.    10 Group      3
[NHFLUX]...XY Node; Nodal moments ->
    1  5.383437555E+15  0.000000000E+00  0.000000000E+00 -6.563766315E+14......
    2  5.645366755E+15  5.024509030E+13  0.000000000E+00 -7.302508118E+14......
    3  5.497814722E+15 -1.274394123E+14  0.000000000E+00 -7.082325292E+14......
    4  5.636631053E+15 -3.728648709E+13 -2.152736329E+13 -7.415886790E+14......
    5  5.012895724E+15 -4.076770938E+13  0.000000000E+00 -6.037342901E+14......
    6  5.375186462E+15 -8.950793860E+13  4.773171664E+13 -6.901478368E+14......
    7  5.375186462E+15 -3.417090136E+12 -1.013820069E+14 -6.901478368E+14......
    8  5.078447736E+15  9.027716722E+11  0.000000000E+00 -6.548752212E+14......
    9  5.160514697E+15 -2.811683332E+13  3.785713716E+13 -6.622498347E+14......
   10  5.264928133E+15 -6.068717139E+13 -3.503775469E+13 -6.891146895E+14......
   11  5.160514698E+15  1.872682586E+13 -4.327846048E+13 -6.622498347E+14......
   12  4.732764069E+15 -2.253257041E+14  0.000000000E+00 -6.228222594E+14......
   13  4.978491353E+15 -7.752316482E+13 -1.786007171E+13 -6.617031496E+14......
   14  4.934763894E+15 -1.001224903E+14 -1.037262894E+14 -6.385351943E+14......
   15  4.934763895E+15 -1.398908468E+14 -3.484547532E+13 -6.385351943E+14......
   16  4.978491353E+15 -5.422885820E+13 -5.820699423E+13 -6.617031497E+14......
   17  3.719037629E+15 -2.008174305E+14  0.000000000E+00 -4.602976941E+14......
   18  4.412309072E+15 -2.349340816E+14  6.228035013E+13 -5.858733063E+14......
   19  4.647043965E+15 -8.931890453E+13 -1.029981137E+14 -6.135248708E+14......
   20  4.382740948E+15 -7.332289739E+13 -4.233299452E+13 -5.397420407E+14......
  ......
```

Output.VARPOW using ISOTXS input

```
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.    10 Group      3
[NHFLUX]...XY Node; Nodal moments ->
    1  5.383439229E+15  0.000000000E+00  0.000000000E+00 -6.563767766E+14......
    2  5.645368422E+15  5.024508611E+13  0.000000000E+00 -7.302509660E+14......
    3  5.497816344E+15 -1.274394329E+14  0.000000000E+00 -7.082326781E+14......
    4  5.636632697E+15 -3.728649825E+13 -2.152736973E+13 -7.415888331E+14......
    5  5.012897277E+15 -4.076772237E+13  0.000000000E+00 -6.037344227E+14......
    6  5.375188047E+15 -8.950795701E+13  4.773171552E+13 -6.901479818E+14......
    7  5.375188047E+15 -3.417100308E+12 -1.013820223E+14 -6.901479818E+14......
    8  5.078449210E+15  9.027415068E+11  0.000000000E+00 -6.548753565E+14......
    9  5.160516210E+15 -2.811685549E+13  3.785713192E+13 -6.622499731E+14......
   10  5.264929659E+15 -6.068719287E+13 -3.503776709E+13 -6.891148317E+14......
   11  5.160516210E+15  1.872681024E+13 -4.327847706E+13 -6.622499732E+14......
   12  4.732765372E+15 -2.253257680E+14  0.000000000E+00 -6.228223797E+14......
   13  4.978492750E+15 -7.752320535E+13 -1.786007816E+13 -6.617032811E+14......
   14  4.934765311E+15 -1.001225253E+14 -1.037263123E+14 -6.385353246E+14......
   15  4.934765312E+15 -1.398908841E+14 -3.484549420E+13 -6.385353247E+14......
   16  4.978492750E+15 -5.422888406E+13 -5.820702610E+13 -6.617032811E+14......
   17  3.719038703E+15 -2.008174785E+14  0.000000000E+00 -4.602977861E+14......
   18  4.412310267E+15 -2.349341448E+14  6.228035306E+13 -5.858734170E+14......
   19  4.647045237E+15 -8.931895077E+13 -1.029981313E+14 -6.135249887E+14......
   20  4.382742230E+15 -7.332292602E+13 -4.233301105E+13 -5.397421512E+14......
  ......
```

Output.VARPOW using PMATRX input

Figure 3-18. Fast Neutron Flux Comparison Between ISOTXS and PMATRX Inputs

For the Case 3 tests, the number of spatial moments included in the error measure was restricted to the stated spatial moments for the P and T options which will be discussed later. Ignoring those results and focusing on the rest of the results, a quick review indicates that the differences for the MaterialPower.out file are consistent with the preceding hand calculation results but there is a notably larger difference for the Output.VARPOW result (as high as 8% for case 3). As stated earlier, the duplicate program takes its input from the PrintTables output for PMATRX, GHFLUX, and NHFLUX and truncation error is expected to be an issue.

Starting with the MaterialPower.out file comparison, the differences are easy to identify as truncation related errors associated with the input to the duplicate program. For the Output.VARPOW file comparison, the result is not as clear. To display the issue, Figure 3-19 provides an excerpt of the PrintTables output for Output.VARPOW at the location where the peak ~8% difference occurs along with the detailed difference calculation output from the duplicate program. The ~8% difference result is highlighted for clarity. As can be seen, the 68th spatial moment of the neutron power density in the cladding material in the 15th XY-mesh on plane 20 has an absolute value that is many orders of magnitude lower than that the neighboring moments and meshes. This is a “zero” coefficient for the power distribution in that it does not contribute any real shape to the flux in this mesh. While it is possible that the NHFLUX and GHFLUX files have “zeros” for this spatial moment at this mesh for all neutron and gamma energy groups, from experience, this zero actually occurs because the various contributions from all of the neutron and gamma groups combined with the cross sections end up making this spatial moment effectively zero. Assuming the magnitude of this spatial moment for the neutron and gamma flux were similar to the surrounding spatial moments, it should be clear that the remaining magnitude of this spatial moment can be dominated by the truncation error associated

with the input to the duplicate program. Inspection of the remaining large differences from Table 3.33 further indicated that they also occurred at spatial moments with individually small absolute values of the power density and were observed to primarily occur with higher order spatial moments. It should be noted that this cancellation to zero result can easily occur for any moment starting at linear but it is just unlikely to occur in a real problem for the lower order moments. This of course cannot occur for the 0th order term as it would require the average flux in many groups for that mesh to be negative. It is noted that the same "zero" moment issue is present for the fast flux and that the difference in magnitude of the errors reported for power density versus fast flux occur because the cross sections are not involved in the fast flux calculation.

[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE. 20 Group 2

XY-MESH	MOMENT 66	MOMENT 67	MOMENT 68	MOMENT 69
1	2.694384284E-15	0.000000000E+00	0.000000000E+00	0.000000000E+00
2	-2.215478546E-07	0.000000000E+00	-2.608550872E-07	0.000000000E+00
3	2.879947076E-06	-7.427085759E-15	-1.231874980E-07	0.000000000E+00
4	1.116042875E-07	-5.311454710E-08	-4.606525896E-08	-4.313029613E-09
5	3.934518987E-07	0.000000000E+00	-1.620823690E-07	0.000000000E+00
6	1.294291458E-06	1.725718749E-06	-1.554023590E-06	1.447874858E-07
7	-1.185841337E-06	-1.777110676E-06	1.509610414E-06	-1.487057619E-07
8	-1.496946003E-06	0.000000000E+00	-2.878712850E-07	0.000000000E+00
9	-8.872847577E-07	1.308735370E-06	1.314351572E-06	1.096437457E-07
10	1.334985705E-08	-6.226298824E-09	-5.309186371E-09	-3.592689041E-10
11	-1.793028042E-06	-2.997320988E-08	-2.030541332E-07	-2.177485685E-09
12	2.164828354E-06	0.000000000E+00	-1.053797727E-07	0.000000000E+00
13	-2.481571946E-08	-1.454503919E-08	1.127898701E-08	-1.182686818E-09
14	1.131721637E-06	-1.557259259E-06	-1.370712326E-06	-1.303713209E-07
15	2.176900380E-06	-2.057545131E-08	-5.260735952E-14	-1.436398071E-09
16	2.888741808E-09	2.528315927E-08	-1.749936287E-09	2.402966906E-09
17	7.279087985E-07	0.000000000E+00	-3.012823695E-07	0.000000000E+00
18	9.243284254E-07	1.215112244E-06	-1.124612853E-06	1.019743384E-07
19	-7.107840408E-07	-1.075825980E-06	1.117929566E-06	-8.990989807E-08
20	4.820655129E-07	-2.298053832E-07	-1.995784302E-07	-1.909989167E-08

Power density Moments in Output.VARPOW

Plane 20 Neutron Power Density clading

XY-MESH	MOMENT 66	MOMENT 67	MOMENT 68	MOMENT 69
1	-2.736271093E-09	0.000000000E+00	0.000000000E+00	0.000000000E+00
2	8.135017085E-09	0.000000000E+00	3.301415787E-09	0.000000000E+00
3	1.159910146E-09	1.447448835E-08	-6.460776356E-09	0.000000000E+00
4	-3.366775387E-09	-3.249084510E-09	-3.450883950E-09	-3.881852945E-09
5	-4.809541866E-09	0.000000000E+00	-5.107896438E-09	0.000000000E+00
6	2.199850147E-09	2.761550921E-09	2.450706280E-09	2.904036071E-09
7	2.682006903E-09	2.339425432E-09	2.336353217E-09	2.664939121E-09
8	7.105756837E-09	0.000000000E+00	-5.734413312E-09	0.000000000E+00
9	5.388499628E-09	5.251367526E-09	3.570738729E-09	5.054900829E-09
10	-7.548654828E-08	-7.941979536E-08	-8.272630533E-08	-1.553781266E-07
11	4.996325451E-09	-6.943481348E-09	-6.269553392E-09	-1.141348957E-08
12	4.865555206E-09	0.000000000E+00	3.949126179E-08	0.000000000E+00
13	3.784764560E-08	-3.286900935E-08	3.478669397E-08	-4.418506825E-08
14	5.030632482E-09	5.201215070E-09	1.526036293E-09	4.879253133E-09
15	4.688215846E-09	-1.062385042E-09	7.751650574E-02	-4.530981469E-09
16	-3.321780544E-07	1.741616470E-08	-2.449410273E-07	2.162560037E-08
17	2.040095329E-10	0.000000000E+00	-9.378001876E-11	0.000000000E+00
18	4.416892754E-09	5.497772764E-09	1.354416263E-09	5.393307419E-09
19	7.134652240E-09	5.978389431E-09	2.128742681E-09	6.208361068E-09
20	-2.581212940E-09	-2.726657926E-09	-2.558973007E-09	-3.036504226E-09

Relative Difference Results

Figure 3-19. Location of Maximum Relative Difference for Benchmark Case 3

Because the magnitude of the spatial moments beyond 0th order naturally vary and can have different signs from group to group, past experience with comparisons of spatial moments results like that being done here can be identified by a growing difference as the number of spatial moments is increased beyond the 0th order term (i.e. the MaterialPower.out file). This is why the additional results were included in Table 3.33 for the case 3 test. As seen, the comparison was limited to the first 10 moments (2nd order) and the first 4 moments (1st order) while the full vector input is 6th order. The maximum difference observed in these extra comparison lines is seen to reduce by several orders of magnitude from the 6th order check to the 1st order restricted check and slightly less to the 2nd order restricted check. This behavior is consistent with past experience and no additional effort is made to investigate the results.

3.2.3 Verification of the VARPOW Behavior when PMATRX is Missing Isotopes

For benchmark case 3, the PMATRX file has fewer isotopes than the ISOTXS file as denoted in Table 3.32. In these situations, VARPOW will issue warnings as occurred for case 3 as shown in Figure 3-20. The issue of course is that without heating cross section data, these isotopes cannot contribute to the power density calculation and thus this should be considered a problem, especially if isotopes like U-233 are important for the fuel cycle analysis as this one has no heating data available. Using the same equations and methodology as VARPOW, the duplicate

program reproduces the results of VARPOW as shown in Table 3.33. This therefore verifies that VARPOW correctly notifies the user that the data is missing and excludes these isotopes from the power density calculation.

```
[VARPOW]...PMATRX mapping failed for the following ISOTXS isotopes:
[VARPOW]...LFP35   LFP38   LFP39   LFP40   LFP41   LFPPX   LFPPI   LFPPY   LFPPM   LFPPZ   LFPPO   LFPPB   C241X   C241I
[VARPOW]...C241Y   C241M   C241Z   C241O   C241B   X135    T232X   T232I   T232Y   T232M   T232Z   T232O   T232B   U233X
[VARPOW]...U233I   U233Y   U233M   U233Z   U233O   U233B   U237X   U237I   U237Y   U237M   U237Z   U237O   U237B   N238X
[VARPOW]...N238I   N238Y   N238M   N238Z   N238O   N238B   P237X   P237I   P237Y   P237M   P237Z   P237O   P237B   P243X
[VARPOW]...P243I   P243Y   P243M   P243Z   P243O   P243B   P244X   P244I   P244Y   P244M   P244Z   P244O   P244B   P233X
[VARPOW]...P233I   P233Y   P233M   P233Z   P233O   P233B   S149    U313    U513    P913    U323    U333    U523    U533
[VARPOW]...P923    P933    LFPP3   LFPP5   LFPP9   DUMP1   DUMP2   DUMP3   DUMP4   TA      NB      FP35    RE35    FP38
[VARPOW]...RE38    FP39    RE39    FP40    RE40    FP41    RE41
```

Figure 3-20. VARPOW Output Excerpt Indicating Missing Isotopes in the PMATRX File

As mentioned earlier, benchmark case 3 uses cross section data generated with ENDF/B-V data and the dataset is over 20 years old. It is not clear today why so many isotopes are not present in the PMATRX file, but this issue is not present using the ENDF/B-VII.0 library with the latest version of the MC^2-3. No effort was done to "fix" this benchmark as the original MC^2 inputs are not available and the case 1 and 2 results which do not have this issue negates the need to be concerned about it.

3.2.4 Hand Calculation Verification for Case 1, 2, and 3

To solidify confidence in the VARPOW results for these three benchmark cases, hand calculations are again done but only for a set of randomly selected spatial mesh and spatial moment of a randomly chosen output vector. The T, P, and S options of iOutput were randomly selected for this verification also. Because the data required for these hand calculations are large (33 group neutron and 21 group gamma), companion Excel files are again used to carry out the calculations which are provided with the verification test suite.

The Excel files were created similarly to the method for the earlier two-dimensional problem although they only include the extracted data at the selected meshes and moments from GHFLUX and NHFLUX. The PrintTables outputs are included with the verification test suite and they can be obtained again by running PrintTables after the DIF3D execution is completed. Given those files, the values that appear in the Excel documents can be identified in those output files and one will find they correspond to the stated mesh and spatial moment. Because the PMATRX input path (GAMSOR) is the preferred one for VARPOW, all of the hand calculations are done using the PMATRX input.

Table 3.34 shows the hand calculation results for the 'MaterialPower.out' file while Table 3.35 shows the results for the 'Output.VARPOW' file. Starting with Table 3.34, the first column lists the benchmark case being checked. The second and third column identify the mesh while the fourth column indicates whether the neutron or gamma power distribution result was checked. The fifth column indicates which material component of the 'MaterialPower.out' file was checked. As can be seen, the relative error of the hand calculation has a very small error.

Table 3.34. Verification of the MaterialPower.out File for Cases 1, 2 and 3

Benchmark	XY Mesh	Axial Plane	power source	Region	VARPOW Result	Hand Calculation Relative Error
Case 1	1	N/A	Neutron	Fuel	6.84685E-05	-3.99E-10
Case 2	3	7	Neutron	Structure	3.14414E-09	2.01E-08
Case 3	2	14	Gamma	Fuel	6.45017E+01	1.74E-08

Continuing with Table 3.35, the first three columns are identical to the purpose of those columns in Table 3.34. The fourth column indicates which part (as is appropriate) of the neutron or gamma power density result is being checked. The fifth column lists the spatial moment chosen for comparison which were intentially chosen to be values <10 to ensure the PrintTables output excerpt would be traceable (84 spatial moments means 85 columns of output in NHFLUX/GHFLUX which does not fit on a sheet of paper). The last two columns show the VARPOW calculated result and the hand calculation of the error.

Table 3.35. Verification of the Output.VARPOW file For Cases 1, 2, and 3

Benchmark	XY Mesh	Axial Plane	Power Source (Region)	Spatial Moment	VARPOW Result	Hand Calculation Relative Error
Case 1 (iOutput T)	22	N/A	Neutron (Fuel)	2nd	-1.16791E-06	-1.20E-09
	95	N/A	Gamma (Structure)	5th	3.38465E-10	6.98E-09
Case 2 (iOutput P)	3	8	Neutron	3rd	-1.51309E-08	3.88E-08
	18	9	Gamma	7th	-4.27462E-10	5.40E-09
Case 3 (iOutput S)	6	15	Neutron (Coolant)	4th	3.04828E-01	1.35E-09
	27	17	Gamma (Structure)	9th	4.09798E-02	-9.11E-09

For completeness, the excerpts of the 'MaterialPower.out' file used in these calculations are shown in Figure 3-21 through Figure 3-23 for the three cases. In each figure, the power density point selected for verification is highlighted. For case 1, it is relatively easy to identify the value because the NHFLUX and GHFLUX have the same 1:NINTXY layout. The fuel material component of the neutron power density corresponds to the 1st column of output.

For cases 2 and 3, finding the row corresponding to the desired axial plane requires some calculation. For case 2, the selected XY mesh (1:NINTXY) is 3 and the 7th axial plane was chosen. The total number of XY meshes for this problem is 271 (=NINTXY). The output row can be calculated as 271*(7-1)+3=1629 which means the 1631st line of output (The file always has 2 comments lines) must be used for the comparison in the hand calculation. The structural material component of the neutron power density corresponds to the 2nd column of output. For case 3, the selected XY mesh is 2 along with the 14th axial plane. The total number of XY

meshes is 79 (=NINTXY) and the row of data can be calculated as 79*13+2=1029. Similar to the previous result, the 1031th line of output should be chosen accounting for the two header lines. The fuel material component of the gamma power density corresponds to the 4th column of output.

```
# This is the VARPOW material power density (watts/cc) for all active meshes
# MatPowerDensity(6,NINTXY,NINTK) NINTXY=   324 NINTK=     1
 6.846845381E-05  2.437787611E-07  2.109979345E-07  2.961173989E-06  2.451476763E-06  3.645022596E-07
 6.726166430E-05  2.394773125E-07  2.072682135E-07  2.909341949E-06  2.408598207E-06  3.581267898E-07
 6.486052462E-05  2.309175749E-07  1.998414686E-07  2.806382156E-06  2.323442619E-06  3.454648754E-07
 6.128543425E-05  2.181759512E-07  1.887723386E-07  2.653910234E-06  2.197377124E-06  3.267181005E-07
 5.655218911E-05  2.013380756E-07  1.741114779E-07  2.460595908E-06  2.035367604E-06  3.026024964E-07
 5.169474787E-05  1.802384402E-07  1.557790268E-07  2.102496150E-06  1.848416862E-06  2.744327690E-07
 4.419914434E-05  1.537847021E-07  1.330007454E-07  1.793696640E-06  1.573627916E-06  2.335502032E-07
 3.465899489E-05  1.206279514E-07  1.048724461E-07  1.354401260E-06  1.172231981E-06  1.734713220E-07
 4.849950465E-06  9.060120108E-08  7.788319122E-08  2.089363797E-07  8.381057757E-07  1.142511821E-07
 3.354508053E-06  5.463475343E-08  4.774024790E-08  1.249917813E-07  5.038603227E-07  6.850186347E-08
 1.671162290E-06  3.028391887E-08  2.780215678E-08  9.831384731E-07  2.434237625E-07  3.631437801E-08
 1.020864504E-06  1.893049477E-08  1.773672413E-08  7.448978910E-07  1.894619215E-07  2.816548085E-08
 1.817435908E-09  3.492965178E-08  5.175608295E-09  6.514163038E-09  4.801928702E-07  8.625907179E-09
 1.423339536E-09  1.967514112E-08  2.972647320E-09  4.994549467E-09  3.668762440E-07  6.404871705E-09
 7.498722752E-10  1.042164196E-08  1.572658779E-09  2.620820616E-09  1.930055984E-07  3.362375460E-09
 3.597345533E-07  1.560778339E-09  5.308800000E-10  5.495305741E-09  2.096407114E-08  1.002169227E-09
 6.250110329E-08  3.185274237E-10  1.078203288E-10  1.929450102E-09  7.379801726E-09  3.523453866E-10
 1.164552737E-08  6.030602661E-11  2.062279328E-11  6.570039888E-10  2.512427888E-09  1.202867623E-10
 6.764604095E-05  2.408678806E-07  2.084704104E-07  2.926110669E-06  2.422479394E-06  3.601911821E-07
 6.646396173E-05  2.366532203E-07  2.048156669E-07  2.875347741E-06  2.380487511E-06  3.539475511E-07
 6.411512181E-05  2.282772675E-07  1.975474811E-07  2.774664747E-06  2.297221971E-06  3.415666960E-07
 .......
```

Figure 3-21. MaterialPower.out Excerpt of Selected Point for Case 1 Hand Calculation

```
# This is the VARPOW material power density (watts/cc) for all active meshes
# MatPowerDensity(6,NINTXY,NINTK) NINTXY=   271 NINTK=    20
 8.897002942E-12  1.018543609E-10  1.540309970E-11  3.897528608E-11  2.882721050E-09  5.019429147E-11
 8.632496147E-12  9.870278021E-11  1.492348071E-11  3.784142717E-11  2.798811176E-09  4.873463086E-11
 8.632496147E-12  9.870278018E-11  1.492348071E-11  3.784209270E-11  2.798864118E-09  4.873556236E-11
 8.632496147E-12  9.870278021E-11  1.492348071E-11  3.784142717E-11  2.798811176E-09  4.873463086E-11
 8.632496147E-12  9.870278018E-11  1.492348071E-11  3.784209270E-11  2.798864118E-09  4.873556236E-11
.....
 1.033677708E-10  9.457623152E-09  1.220137090E-09  1.007677183E-09  6.994883533E-08  1.307046141E-09
 7.542910233E-07  3.144139153E-09  2.667394656E-09  3.175314642E-08  2.556511061E-08  3.798945576E-09
 7.542910234E-07  3.144139153E-09  2.667394656E-09  3.175228919E-08  2.556412702E-08  3.798799275E-09
 7.542910233E-07  3.144139153E-09  2.667394656E-09  3.175314642E-08  2.556511061E-08  3.798945576E-09
 7.542910234E-07  3.144139153E-09  2.667394656E-09  3.175228919E-08  2.556412702E-08  3.798799275E-09
.....
```

Figure 3-22. MaterialPower.out Excerpt of Selected Point for Case 2 Hand Calculation

```
# This is the VARPOW material power density (watts/cc) for all active meshes
# MatPowerDensity(6,NINTXY,NINTK) NINTXY=    79 NINTK=    29
-2.048844415E-04  1.514845572E-04  2.326943864E-04  1.929998551E-03  4.613451985E-02  1.070996202E-02
-2.022296014E-04  1.495845688E-04  2.297445366E-04  1.908092814E-03  4.561968029E-02  1.058997351E-02
-1.942005428E-04  1.438109295E-04  2.207929692E-04  1.826038931E-03  4.365114790E-02  1.013331903E-02
-1.968869555E-04  1.457471495E-04  2.237929604E-04  1.854021141E-03  4.432345753E-02  1.028924448E-02
-1.806543066E-04  1.339885395E-04  2.055999174E-04  1.696826915E-03  4.056649257E-02  9.416942916E-03
.....
-9.562107654E-03  4.742251998E-01  3.073825025E+00  5.610776946E-02  4.274771581E+00  4.428513207E+00
 6.769545315E+02  1.389536219E+00  1.268322010E+00  6.450168581E+01  1.257965244E+01  1.902466294E+00
 6.317624329E+02  1.300577083E+00  1.187078423E+00  6.022638802E+01  1.170225378E+01  1.769426265E+00
 6.541731366E+02  1.365672026E+00  1.247235752E+00  6.277265899E+01  1.229414188E+01  1.860576729E+00
-2.273360914E-02  1.111619772E+00  2.058924804E+00  1.504869874E-01  1.057693252E+01  3.046423146E+00
```

Figure 3-23. MaterialPower.out Excerpt of Selected Point for Case 3 Hand Calculation

The excerpts of the PrintTable outputs of Output.VARPOW used in the hand calculation are shown in Figure 3-24 through Figure 3-26. The selected power density moment is highlighted in each figure. When searching for the targeted point in the Output.VARPOW file, both the radial and axial mesh index are easy to find as they are shown explicitly in the output as seen

in each figure. Note that the group index in Output.VARPOW corresponds to specific components of the power density (or fast flux) and not energy group as discussed earlier.

For case 1 in Figure 3-24, the iOption=T means that group 1 corresponds to the fuel material component of the neutron power density and group 5 corresponds to the structure material component of the gamma power density. For case 2 in Figure 3-25, the iOption=P means that group 1 corresponds to the neutron power density and group 2 corresponds to the gamma power density. For case 3 in Figure 3-26, the iOption=S means that group 3 corresponds to the coolant material component of the neutron power density and group 5 corresponds to the structure material component of the gamma power density. Note that for iOutput=S in case 3, the results are for the normalized monomial data which not only requires the 0^{th} moment to do the normalization, but all of the polynomial moments (all columns) in order to construct the monomial distribution and the $\hat{F}$ matrix. The detailed calculation is in the companion Excel file.

To calculate the power densities, the neutron and gamma flux (moments) for all respective energy groups are needed along with the needed cross sections. Providing excerpts of this output is unrealistic here and the PrintTable outputs of NHFLUX and GHFLUX are not shown for brevity. For traceability, the values in the Excel files can be searched for in the PrintTables outputs of NHFLUX and GHFLUX as is desired. For the same reasons, the PMATRX data and follow-on zone macroscopic heating cross sections are not shown but the calculation is provided in the companion Excel files.

```
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      1
[NHFLUX]...XY Node; Nodal moments ->
    1  6.846845381E-05 -1.745353403E-07 -1.188071551E-07 -4.504910837E-08  5.174798488E-10 -3.068723379E-08  2.087011848E-11  1.074556832E-10  1.066383188E-10...
    2  6.726166430E-05 -5.217081193E-07 -1.151471999E-07 -4.457239330E-08  1.611986677E-09 -2.975477691E-08  5.658605334E-11  1.200296262E-10  3.320410782E-10...
    3  6.486052462E-05 -8.637558338E-07 -1.073626626E-07 -4.377567186E-08  2.926369386E-09 -2.777686824E-08  6.967523855E-11  1.539937531E-10  6.021603776E-10...
    4  6.128543425E-05 -1.199592690E-06 -9.417949349E-08 -4.309573154E-08  4.791693222E-09 -2.444620199E-08  2.485781755E-11  2.372079563E-10  9.839725249E-10...
    5  5.655218911E-05 -1.533634582E-06 -7.239289188E-08 -4.363843321E-08  8.065180820E-09 -1.900206395E-08 -1.697284921E-10  4.564731050E-10  1.648901581E-09...
    6  5.169474787E-05 -1.930879651E-06 -3.415525632E-08 -5.575838621E-08  1.558630630E-08 -9.680282916E-09 -7.589440266E-10  1.150364197E-09  3.145721733E-09...
.....
   21  6.411512181E-05 -8.441543088E-07 -3.232904836E-07 -4.248646763E-08  8.252485382E-09 -2.804992398E-08  1.054835085E-10  4.206063751E-10  4.950848040E-10...
   22  6.062769845E-05 -1.167914706E-06 -2.865857599E-07 -4.114541241E-08  1.318413074E-08 -2.540554533E-08  1.128591691E-10  6.109131094E-10  7.431587017E-10...
   23  5.603648814E-05 -1.481616644E-06 -2.280935144E-07 -3.999488118E-08  2.117561128E-08 -2.157759493E-08  6.703217060E-11  1.072714027E-09  1.045176067E-09...
   24  5.141778853E-05 -1.834919737E-06 -1.333351191E-07 -4.710047460E-08  3.745973015E-08 -1.675830551E-08 -2.911735553E-11  2.346702748E-09  1.340237864E-09...
   25  4.442333472E-05 -2.204756864E-06  5.466188660E-08 -4.824732405E-08  7.569456985E-08 -1.121643957E-08 -1.459456899E-11  6.217606524E-09  7.553731005E-10...
.....
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     1 Group      5
[NHFLUX]...XY Node; Nodal moments ->
    1  2.451476763E-06 -6.204734280E-09 -4.195388310E-09 -1.601183003E-09  1.857000085E-11 -1.083025672E-09  9.222188322E-13  3.857912857E-12  3.825207170E-12...
    2  2.408598207E-06 -1.852832815E-08 -4.063747688E-09 -1.579110604E-09  5.809609527E-11 -1.049527654E-09  2.772018453E-12  4.364408756E-12  1.196072685E-11...
    3  2.323442619E-06 -3.058787477E-08 -3.781481393E-09 -1.532266599E-09  1.067200208E-10 -9.779338183E-10  5.287929909E-12  5.790229686E-12  2.194863418E-11...
    4  2.197377124E-06 -4.208023905E-08 -3.294045273E-09 -1.417170189E-09  1.794756550E-10 -8.551443739E-10  1.779471286E-11  9.507285334E-12  3.684897409E-11...
    5  2.035367604E-06 -5.032422751E-08 -2.454608277E-09 -1.205443432E-10  3.182175566E-10 -6.462546878E-10  4.857856543E-10  1.944870656E-11  6.538779097E-11...
.....
   94  1.873131925E-06 -3.183550365E-08 -3.474104041E-08 -1.009268746E-09  6.810202695E-10 -2.820507557E-09  1.216254005E-11  1.161317660E-11  3.804788077E-11...
   95  1.750528733E-06 -3.867511691E-08 -3.271610207E-08 -7.651965172E-10  8.384652308E-10 -2.567595456E-09  2.269645398E-11 -1.178779134E-10  1.479806066E-10...
   96  1.605526115E-06 -4.543388721E-08 -3.214184260E-08 -9.840942249E-10  5.103424876E-10 -1.231333742E-09  1.972921374E-11  1.592742302E-10  1.404680080E-10...
   97  1.436044890E-06 -5.210334966E-08 -2.882518690E-08 -7.098284049E-10  1.229539108E-09 -1.116668618E-09  1.558770044E-11  1.449360104E-11 -8.602975695E-12...
   98  1.246767521E-06 -5.705693761E-08 -2.442430964E-08 -6.047016586E-10  1.287385477E-09 -1.208723859E-09 -6.002294959E-12 -5.764588800E-12 -2.143381012E-11...
   99  1.039531321E-06 -6.315889177E-08 -1.999293444E-08 -1.196048785E-09  1.298937245E-09 -1.296946696E-09 -1.327388495E-10  1.207679195E-11  1.996806534E-12...
  100  7.851789575E-07 -9.099992670E-08 -1.487724938E-08 -9.152493242E-09  1.797274637E-09 -1.150694813E-09 -2.352416463E-09  1.594838083E-10  7.557063024E-11...
.....
```

Figure 3-24. Excerpt of PrintTables Output of Output.VARPOW for Case 1 Verification

```
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     8 Group      1
[NHFLUX]...XY Node; Nodal moments ->
    1  1.065161209E-08  0.000000000E+00  0.000000000E+00  2.171803734E-10  2.644646996E-10  0.000000000E+00  3.696350336E-10  0.000000000E+00  0.000000000E+00...
    2  7.501794445E-07 -1.747164090E-08  0.000000000E+00  1.405645655E-08  2.484464152E-09  0.000000000E+00 -2.102998113E-09 -3.018464529E-10  0.000000000E+00...
    3  7.501794445E-07 -8.735820451E-09 -1.513088487E-08  1.405645655E-08 -1.473232703E-09  2.809597552E-09  7.286358362E-10 -1.509232267E-10 -2.614066967E-10...
    4  7.501794445E-07  8.735820451E-09 -1.513088487E-08  1.405645655E-08 -1.473232703E-09 -2.809597553E-09  7.286358361E-10  1.509232265E-10 -2.614066963E-10...
    5  7.501794445E-07  1.747164090E-08  0.000000000E+00  1.405645655E-08  2.484464151E-09  0.000000000E+00 -2.102998112E-09  3.018464534E-10  0.000000000E+00...
.....
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.     9 Group      2
[NHFLUX]...XY Node; Nodal moments ->
    1  6.271627365E-08  0.000000000E+00  0.000000000E+00  3.625895924E-09  4.195290974E-09  0.000000000E+00  5.863642756E-09  0.000000000E+00  0.000000000E+00...
    2  5.314574582E-08  1.395661049E-09  0.000000000E+00  2.989067677E-09 -7.332889957E-10  0.000000000E+00  2.510356174E-10  7.422939030E-11  0.000000000E+00...
    3  5.314394828E-08  6.985438212E-10  1.209913390E-09  2.990451423E-09  1.723419351E-10 -6.430664111E-10 -3.971843468E-10  3.690669332E-11  6.392426796E-11...
    4  5.314574582E-08 -6.978305247E-10  1.208677924E-09  2.989067677E-09  1.724215794E-10  6.429704718E-10 -3.969778375E-10 -3.711469515E-11  6.428453771E-11...
    5  5.314394828E-08 -1.397087642E-09  0.000000000E+00  2.990451423E-09 -7.335037834E-10  0.000000000E+00  2.509258000E-10 -7.381338663E-11  0.000000000E+00...
.....
   17  5.154564484E-08 -6.503475409E-15  1.125712476E-09  2.894530759E-09 -9.820741858E-11 -5.724302613E-14 -2.992044240E-10  2.363588001E-13  5.985915907E-11...
   18  4.869543347E-08 -1.418464140E-09  2.456851959E-09  2.743203560E-09  5.956763157E-11  5.147241741E-10 -4.274624382E-10 -7.523098454E-11  1.303038875E-10...
   19  5.154564484E-08 -9.748923493E-10  5.628618700E-10  2.894530759E-09 -2.132013323E-10  8.157776605E-11 -2.169291306E-10 -5.195773180E-11  2.972488682E-11...
   20  4.830419392E-08 -4.217592040E-09  0.000000000E+00  2.832110434E-09  3.342238614E-09  0.000000000E+00  4.657951010E-09 -2.287917525E-10  0.000000000E+00...
.....
```

Figure 3-25. Excerpt of PrintTables Output of Output.VARPOW for Case 2 Verification

```
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.    15 Group      3
[NHFLUX]...XY Node; Nodal moments ->
    1  9.896084482E-01  0.000000000E+00  0.000000000E+00  2.211328026E-01  8.022585977E-02  0.000000000E+00  8.022585978E-02  0.000000000E+00  0.000000000E+00...
    2  1.011195089E+00  1.264045851E-02  0.000000000E+00  2.486359080E-01 -1.025717201E-01  0.000000000E+00  1.033640976E-02  2.629448997E-02  0.000000000E+00...
    3  1.011319880E+00 -2.155347168E-01  0.000000000E+00  2.902468780E-01 -1.650747672E-01  0.000000000E+00  5.310899467E-02  2.083634454E-02  0.000000000E+00...
    4  1.010206972E+00 -6.601505717E-02 -3.811381104E-02  2.662617995E-01 -3.543905306E-02  2.660757839E-02 -5.080094562E-02  5.094690845E-03  2.941421120E-03...
    5  8.802751418E-01 -7.538210812E-02  0.000000000E+00  4.315131518E-01  6.035920294E-01  0.000000000E+00  5.806941530E-01  1.057679705E-03  0.000000000E+00...
    6  1.011439642E+00 -1.432399542E-01  1.013780917E-01  3.048279792E-01  1.186674566E-02  2.289774195E-01 -1.308565627E-01  7.995692811E-03 -2.033271829E-02...
    7  1.011439642E+00  1.617602570E-02 -1.747384851E-01  3.048279792E-01  3.974395521E-03  2.380907206E-01 -1.229642126E-01 -1.361080415E-02  1.709083222E-02...
.....
.....
[NHFLUX]...REGULAR FLUX MOMENTS FOR AXIAL PLANE.    17 Group      5
[NHFLUX]...XY Node; Nodal moments ->
    1  1.094710530E+00  2.360507712E-04  0.000000000E+00  9.459183375E-01 -5.835566036E-01  7.206144490E-04 -5.835566035E-01 -3.535483228E-05  0.000000000E+00...
    2  9.228492733E-01 -2.511835923E-01  1.383558849E-04  1.032070920E+00  4.710703863E-01 -5.700586635E-04 -1.176289530E-01 -3.782700057E-02 -3.454461796E-05...
    3  9.254085027E-01  7.284032276E-02 -5.683316359E-05  1.005075580E+00  4.553640026E-01 -1.662077969E-04 -9.868799001E-02 -2.030729415E-01 -2.393857344E-03...
    4  9.424439534E-01 -7.964481149E-02 -4.597945524E-02  1.105943881E+00 -1.778877440E-02  2.058853736E-02 -3.021376772E-02 -1.111280220E-01 -6.487191333E-02...
    5  1.074499586E+00 -1.445082056E-01 -3.178866188E-05  8.507108097E-01 -5.288406660E-01  1.687968455E-04 -5.497543916E-01 -8.015788829E-02  1.598038079E-03...
.....
   26  9.054261710E-01 -3.735796825E-01 -4.784785796E-02  9.988510206E-01  7.827240699E-01  8.799719269E-03 -1.425866025E-01  4.246534356E-03 -7.482004322E-02...
   27  9.054717243E-01 -2.282176640E-01 -2.995371935E-01  9.984932819E-01  9.284425830E-02  8.054654902E-01  5.477813725E-01 -6.247653338E-02  4.097975035E-02...
   28  9.326720496E-01 -5.067229181E-02 -1.033335613E-01  1.183834676E+00 -1.350451197E-02  3.659483532E-02 -6.980464037E-02 -6.148443165E-02 -1.291244555E-01...
   29  9.053522906E-01 -3.761543537E-01 -2.481095957E-01  9.697703996E-01  8.275022872E-01 -2.604258001E-02 -2.080767567E-01 -2.329167003E-02 -3.868785633E-01...
   30  9.704004867E-01 -5.142111700E-01 -7.939305089E-05  5.456834032E-01  7.370326088E-02  3.302625633E-04 -3.167079682E-02 -5.177306022E-01 -1.615028453E-04...
.....
```

Figure 3-26. Excerpt of PrintTables Output of Output.VARPOW for Case 3 Verification

3.2.5 Verification VARPOW screen output for 3D core model

The two output files ‘MaterialPower.out’ and ‘Output.VARPOW’ are of course the primary outputs of interest from VARPOW. But VARPOW also outputs the mesh power from ‘MaterialPower.out’ in a more readable format as shown in Figure 3-27. This output is of course identical in concept to the data in ‘MaterialPower.out’ but it is more readable as it includes the XY and axial mesh index information, the region label associated with the mesh and the volume of the mesh. The layout is of course different as the screen output is grouped by XY mesh (Assembly #) instead of by axial plane. The screen output values are reported in total power (Watts) instead of power density (W/cc) but given the mesh volume is provided in the screen output, it is a trivial matter to convert it back to the power density.

```
[VARPOW]...Assembly wise dump of hexagonal assembly power details
[VARPOW]...Assembly    1 in ring   1 position      1 at GEODST I=   10 J=   10
[VARPOW]...|Axial|Region|          |        Neutron Heating (Watts)        |         Gamma Heating (Watts)         |
[VARPOW]...|Index|Label |Volume(cm^3)|    Fuel     | Structure  |  Coolant   |    Fuel     | Structure  |  Coolant   |
[VARPOW]...|   20|REFL  | 3.24760E+03| 4.32962E-11| 1.62484E-10| 2.34956E-11| 2.38224E-10| 1.76460E-08| 3.07221E-10|
[VARPOW]...|   19|REFL  | 3.24760E+03| 1.45865E-10| 5.57211E-10| 8.04285E-11| 7.56054E-10| 5.59261E-08| 9.73677E-10|
[VARPOW]...|   18|REFL  | 3.24760E+03| 2.99092E-10| 1.49374E-09| 2.15171E-10| 1.41101E-09| 1.04277E-07| 1.81605E-09|
[VARPOW]...|   17|CR01  | 3.57235E+03| 8.39915E-07| 1.72963E-09| 1.45628E-09| 1.48055E-08| 6.73496E-08| 8.53143E-09|
[VARPOW]...|   16|CR01  | 3.57235E+03| 2.35444E-06| 6.01700E-09| 5.12750E-09| 3.95916E-08| 1.80135E-07| 2.28118E-08|
[VARPOW]...|   15|CR01  | 3.57235E+03| 6.64346E-06| 2.07754E-08| 1.80312E-08| 1.04819E-07| 4.76949E-07| 6.03840E-08|
[VARPOW]...|   14|CR01  | 3.57235E+03| 1.75711E-05| 7.02254E-08| 6.24817E-08| 2.56907E-07| 1.16877E-06| 1.47907E-07|
[VARPOW]...|   13|CR01  | 3.57235E+03| 4.26614E-05| 2.35279E-07| 2.15284E-07| 5.69358E-07| 2.58165E-06| 3.26701E-07|
[VARPOW]...|   12|CR01  | 3.57235E+03| 9.03037E-05| 8.16227E-07| 7.50541E-07| 1.37169E-06| 5.92211E-06| 7.69926E-07|
[VARPOW]...|   11|CR01  | 3.89711E+03| 2.07968E-04| 3.34022E-06| 2.95775E-06| 5.25265E-06| 2.08174E-05| 2.89098E-06|
[VARPOW]...|   10|EMPD  | 3.24760E+03| 2.26922E-07| 1.89301E-05| 2.46539E-06| 2.01236E-06| 1.40438E-04| 2.62595E-06|
[VARPOW]...|    9|EMPD  | 3.24760E+03| 2.95984E-07| 2.64562E-05| 3.41467E-06| 2.83819E-06| 1.97155E-04| 3.68363E-06|
[VARPOW]...|    8|EMPD  | 3.24760E+03| 3.31075E-07| 3.03454E-05| 3.91564E-06| 3.22837E-06| 2.24083E-04| 4.18713E-06|
[VARPOW]...|    7|EMPD  | 3.24760E+03| 3.35697E-07| 3.07145E-05| 3.96251E-06| 3.27253E-06| 2.27166E-04| 4.24476E-06|
[VARPOW]...|    6|EMPD  | 3.24760E+03| 3.10723E-07| 2.74970E-05| 3.54680E-06| 2.97174E-06| 2.06516E-04| 3.85846E-06|
[VARPOW]...|    5|EMPD  | 3.24760E+03| 2.63888E-07| 2.04021E-05| 2.65863E-06| 2.24219E-06| 1.56652E-04| 2.92581E-06|
[VARPOW]...|    4|EMPD  | 3.89711E+03| 2.38164E-07| 1.09882E-05| 1.52965E-06| 1.12565E-06| 8.17896E-05| 1.52142E-06|
[VARPOW]...|    3|REFL  | 3.24760E+03| 1.39582E-07| 2.91179E-06| 4.36150E-07| 5.06622E-07| 3.68550E-05| 6.49530E-07|
[VARPOW]...|    2|REFL  | 3.24760E+03| 8.04145E-08| 1.05445E-06| 1.60404E-07| 3.28864E-07| 2.42320E-05| 4.21979E-07|
[VARPOW]...|    1|REFL  | 3.24760E+03| 2.88939E-08| 3.30782E-07| 5.00230E-08| 1.26576E-07| 9.36191E-06| 1.63011E-07|
[VARPOW]...|Total|      |            | 3.70593E-04| 1.74123E-04| 2.61509E-05| 2.62653E-05| 1.33564E-03| 2.85120E-05|
```

Figure 3-27. Excerpt of VARPOW Screen Output for Case 2, using PMATRX Input

The VARPOW screen output is not used by DASSH, but it provides a more readable information for the user and should be verified. Given the preceding work verifies the MaterialPower.out data, all that needs to be done here is to verify that the screen output is consistent with MaterialPower.out. A simple script was created to check the consistency between screen output and MaterialPower.out which confirmed that the results are the same. To demonstrate it here, the last line (with axial index 1) of output in Figure 3-27 corresponds to the first row of output in Figure 3-28.

```
# This is the VARPOW material power density (watts/cc) for all active meshes
# MatPowerDensity(6,NINTXY,NINTK) NINTXY=   271 NINTK=    20
 8.897002942E-12  1.018543609E-10  1.540309970E-11  3.897528608E-11  2.882721050E-09  5.019429147E-11
 8.632496147E-12  9.870278021E-11  1.492348071E-11  3.784142717E-11  2.798811176E-09  4.873463086E-11
 8.632496147E-12  9.870278018E-11  1.492348071E-11  3.784209270E-11  2.798864118E-09  4.873556236E-11
 8.632496147E-12  9.870278021E-11  1.492348071E-11  3.784142717E-11  2.798811176E-09  4.873463086E-11
 8.632496147E-12  9.870278018E-11  1.492348071E-11  3.784209270E-11  2.798864118E-09  4.873556236E-11
.........
.........
 8.125643175E-11  6.282230170E-09  8.186453501E-10  6.904153359E-10  4.823626214E-08  9.009160471E-10
 5.588016838E-07  2.101515166E-09  1.795949712E-09  2.192664614E-08  1.784044273E-08  2.649950620E-09
 5.588016839E-07  2.101515166E-09  1.795949712E-09  2.192728055E-08  1.784120382E-08  2.650057549E-09
 5.588016838E-07  2.101515166E-09  1.795949712E-09  2.192664614E-08  1.784044273E-08  2.649950620E-09
 5.588016839E-07  2.101515166E-09  1.795949712E-09  2.192728055E-08  1.784120382E-08  2.650057549E-09
.........
```

Figure 3-28. Excerpt of PMATRX Based MaterialPower.out for Case 2

Taking the fuel (neutron) component power of 2.88939E-08 Watts and dividing by the volume 3.24760E+03 cm^3 gives 8.89700E-12 which matches the value shown in Figure 3-28, as marked by blue color. In this manner, all values on this row can be hand calculated and found to match. The only difficulty comes in matching the output lines between the two respective outputs and thus care should be taken in doing this. The assembly # shown in the VARPOW screen output corresponds to the index of XY mesh in MaterialPower.out file, while the axial index in the VARPOW screen output corresponds to the axial plane. The last line with axial index 1 in Figure 3-27, which corresponds to the 3rd line of MaterialPower.out file (the first 2 lines are comments), has already been demonstrated. For the line with axial index 5, the output row can be calculated as 271*(5-1)+1=1085 which means the 1087th line of MaterialPower.out file. Taking the fuel (gamma) component power of 2.24219E-06 Watts and dividing by the

volume 3.24760E+03 cm^3 gives 6.90414E-10 which matches the corresponding value shown in Figure 3-28, as marked by blue color. No additional verification of this output is needed and one can conclude that the screen output is consistent with the MaterialPower.out file.

4 Summary of the Preceding Verification Work

The preceding work verified categories 1 ~ 4 of Table 1.3. The set of test problems are summarized in Table 4.1, along with cross referencing for the section of this report it is discussed in and the category that it satisfies.

Table 4.1. Verification Test Problems and Cross Referencing to Category and Section

Benchmark Index in test suite	Verification Section	Verification Category
17	3.1	1 a) 2 a) b) 3 a) b) 4 a) b)
12	3.2.1	1 a)
	3.2.2, 3.2.3, 3.2.4	2 a) b) 3 a) 4 a) b)
13	3.2.1	1 a)
	3.2.2, 3.2.3, 3.2.4	2 a) b) 3 a) 4 a) b)
16	3.2.1	1 a)
	3.2.2, 3.2.3, 3.2.4	2 a) b) 3 a) 4 a) b)
	3.2.5	1 b)

In this document, the verification work was displayed for the power distribution calculation capabilities of VARPOW. For all identified VARPOW outputs, the work covered in this report demonstrated that the equations, shown in the methodology section of this report, could produce consistent results with the output of VARPOW.

It is noted that the GAMSOR and DIF3D verification report [12][13] ensures the accuracy of the GAMSOR and DIF3D solution that VARPOW relies upon.

5 Conclusion

The VARPOW program is a post-processing utility program for DIF3D, specifically DIF3D-VARIANT, and it was developed to provide power density inputs for DASSH. The basic methodology of VARPOW is to retrieve the neutron and gamma flux distributions calculated by GAMSOR (or GAMSRC) and combine them with the heating cross sections in PMATRX. Alternatively one can obtain the power density distribution from just the neutron flux calculation from DIF3D and ISOTXS. The equations used in VARPOW have been detailed in this report. During this work, some of the input options related with specifying the coolant type were identified to not work properly and thus are not verified at this time. The remaining parts of VARPOW that are working were fully checked.

In addition to the screen output, the VARPOW program generates three interface output files: 1) MaterialPower.out, 2) Output.VARPOW, and 3) VariantMonoExponents.out. The VariantMonoExponents.out file stores the monomial basis and the coefficient matrix to convert a set of polynomial coefficients to a set of monomial coefficients. This file is generated because it is hard to replicate outside of VARPOW without knowledge about the monomial basis. The coefficient matrix was verified in this report given the details on the monomial basis and is used in this report to verify the monomial basis outputs of VARPOW. The MaterialPower.out contains the mesh-wise total power density in the domain while the binary Output.VARPOW file contains the detailed polynomial (or monomial) basis of the spatial power distribution. Both were verified in this report by hand calculations and a duplicate program that replicates the equations VARPOW is using.

The first test case studied was a simple two-dimensional model with quarter core symmetry. By design, this problem had a limited size to make a complete hand calculation tractable for all meshes and moments. A companion Excel document is provided that displays the verification work done. The hand calculation results matched very well and the duplicate program confirmed that aspect.

The next three verification tests were larger and more representative of real problems. For these tests, the duplicate program was able to demonstrate consistency with the VARPOW calculated results. The mesh-averaged neutron and gamma power densities were found to be within the truncation error in all of the tests. The comparison of the higher order spatial moments in Output.VARPOW was found to be severely limited by the truncation error on the input provided to the duplicate program. These issues were traced to the occurance of “zero” coefficients that occur when the NHFLUX, GHFLUX, and PMATRX data are combined which cause some spatial moments to be effectively zero and thus highly dependent upon the truncation error in the various values used in the calculation. It was clearly demonstrated in this report that the difference between the duplicate program and VARPOW decreased as expected. Hand calculations were done and displayed which independently verified the three test problem results from the duplicate program.

The screen output was verified to be consistent with the MaterialPower.out output. Other minor aspects that were verified were the correct identification by VARPOW of missing heating cross section data in PMATRX and the correct usage of the optional AssignIsotope.inp file by VARPOW. With this report and the new, repeatable verification test problems it provides, the VARPOW utility program can be considered verified.

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