SYN2D Summary Notes and Usage
with 1-D Versus 2-D Comparisons for the JPDR

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Overview

One of the goals of the current project was to quantify the error that is introduced with the use of 1-D transport models to determine the neutron flux used in the ex-core activation calculations. For example, two simple 1-D calculations along the core radial and axial centerlines should give a reasonable estimate of the space-energy neutron environment near the core. However, use of this 1-D information in regions far removed from either the axial or radial centerlines of the core is probably questionable -- and this approach clearly can introduce significant uncertainty within the ex-core activity estimates. The goal here was to roughly quantify the typical errors that can be expected with the 1-D approximation.

To obtain the necessary data for the 1-D versus 2-D comparisons, 1-D radial and 1-D axial DORT models for the JPDR system were developed. These models are simple 1-D cuts along the $z = 0$ and $r = 0$ centerlines of the 2-D RZ JPDR model, respectively. The new 47-group neutron cross section library with no upscatter was used for all the 1-D and 2-D calculations.

A short Fortran processing code called SYN2D was written to help facilitate the comparison of the 1-D versus 2-D flux distributions. SYN2D synthesizes the two 1-D flux profiles into a standard 2-D flux distribution, so that direct comparison to the full JPDR RZ model can be made. The synthesis process assumes separability in the two spatial directions and simply generates the 2-D space-energy flux distributions as the product of the two 1-D profiles. Two options are available:

1. Modulate the radial flux profile with an axial distribution function (**isyn** > 0):

$$\Phi_{ijg} = \phi_{ig}\psi_{jg} \qquad \text{and} \qquad \psi_{jg} = \phi_{jg}/\phi_{Jg} \tag{1}$$

2. Modulate the axial flux profile with a radial distribution function (**isyn** < 0):

$$\Phi_{ijg} = \psi_{ig}\phi_{jg} \qquad \text{and} \qquad \psi_{ig} = \phi_{ig}/\phi_{Ig} \tag{2}$$

where

Φ_{ijg} is the synthesized 2-D space-energy flux distribution,

ϕ_{ig} is the flux profile from the 1-D radial model,

ϕ_{jg} is the flux profile from the 1-D axial model, and

ψ_{ig} or ψ_{jg} is the appropriate transverse distribution function which is normalized to unity for each energy group at some specific I or J location.

In standard usage, **isyn** > 0 is normally selected. This uses the 1-D axial model to determine a shape or modulating profile to apply at each radial point from the 1-D radial model. The shape function is normalized to unity for each group at a specific axial location as specified by user input (J = **jjn** in the input to SYN2D). If desired, **isyn** < 0 makes a similar approximation but, this time, the radial profile is used as the shape function to modulate the 1-D axial profile at each space-energy location.

This synthesis procedure is very simple and the result is an approximate neutron flux distribution at each discrete ijg space-energy location throughout the 2-D RZ model. This 2-D flux profile is written in standard form, so that the auxiliary codes in the local computational system (PROCESS, ACTIV, FEWGRP2D, etc.) can read and process the synthesized fluxes as a normal 2-D DORT flux file.

For testing, a global normalization option (specified by **norm** = 1 within the SYN2D input) allows the user to normalize the synthesized 2-D flux, Φ_{ijg}, to some specified value. In particular, an input weight function, w_g (**ewtg** in the input to SYN2D), and a global flux normalization, **xynorm**, forces the synthesized flux, weighted over a particular energy interval, to a specific known value. In equation form, we have

$$\Phi_{ijg}{}^{new} = \alpha\, \Phi_{ijg}{}^{old} \qquad \text{where} \quad \alpha = xynorm \Big/ \sum_g w_g\, \Phi_{IJg}{}^{old} \qquad (3)$$

This option was useful during the testing of SYN2D and it also may be appropriate for routine use if the flux at a specific point is known by some means (via an experimental measurement program or via use of a more accurate computational methodology).

SYN2D Input Description

The new SYN2D code is very easy to use with minimal user input. Listed below are the execution and input instructions for SYN2D. This information is embedded as comments within the code as internal documentation.

```
c
c  ****************************************************************
      PROGRAM syn2d
c
c Original Code (Dec. 1999)
c   This program reads two 1-D flux files from DORT (a 1-D radial model and
c   a 1-D axial model) and creates a 2-D RZ flux distribution.  The method
c   used to do this is not very rigorous.  Actually it is really quite
c   arbitrary, and options have been built into SYN2D to study this dilemma.
c
c   Another real question arises around the normalization issue -- since there
c   is no real correct way to do this (at least not easily). Thus, again SYN2D
c   allows some user options to address this additional dilemma.
c
c   The output of SYN2D is a scalar 2-D flux file that can be read directly by
c   PROCESS/FEWGRP2D/ACTIV etc. for further processing and analysis.
c
c   Fixed file names are used as follows:
c      --> syn2din  -  user input (unit 5)
c      --> syn2dout -  printed output (unit 6)
```

```
c      --> flxini   -  input 1-D x-directed (radial) flux file (nu1)
c      --> flxinj   -  input 1-D y-directed (axial) flux file (nu2)
c      --> flxout   -  2-D RZ scalar flux file (nu3)
c   Note: 1. The format of the flux files is specified via user input
c         2. Unit 8 is used as a scratch file for temporary storage
c
c
c Code author: JRWhite (UMass-Lowell)
c
c **********************************************************************
c
c   EXECUTION INSTRUCTIONS
c
c   The code is executed as part of a batch file that handles the file
c   manipulation as indicated above.
c
c
c   USER INPUT INSTRUCTIONS
c
c       FIDAS Input:
c
c FIDAS INPUT BLOCK #1  (primary dimension setting parameters)
c
c  1$$ Array (15 entries)
c
c1  im = # of mesh in x-dir (radial model)
c   jm = # of mesh in y-dir (axial model)
c   igm = total # of energy groups
c   iflx1 = format of input flux files  (both radial and axial fluxes)
c          (-1/0/1 ascii scalar flux/binary scalar flux/DORT VARFLM)
c   iflx2 = format of the output 2-D scalar flux file
c          (-1/0 ascii scalar flux/binary scalar flux)
c
c6  iin = x-directed i mesh location for local normalization (default to 1)
c   jjn = y-directed j mesh location for local normalization (default to 1)
c   isyn = synthesis option
c     > 0  -- modulate radial profile with axial distribution function
c     < 0  -- modulate axial profile with radial distribution function
c   where
c     |isyn| = 1  simply normalizes the transverse profile to a particular
c                 point for each group.  At this point, the 2-D radial
c                 profile is identical to the 1-D profile.
c       for example: if isyn = 1, the modulating function is
c                         psi(j,g) = flxi(j,g)/flx(jjn,g)
c                     where flx is from the axial model and jjn is input
c                   if isyn = -1, the modulating function is
c                         psi(i,g) = flx(i,g)/flx(iin,g)
c                     where flx is from the radial model and iin is input
c
c     |isyn| = 2  use the channel flux definition for the transverse profile
c                   (be careful with normalization here)
c       for example: if isyn = 2, the modulating function is
c                         psi(j,g) = flx(j,g)/flxg(g)
c                     where flxg(g) is [sum over j of (flx(j,g)*Vj)]
c                     and Vj is the nodal volume in the axial model
c                   if isyn = -2, the modulating function is
c                         psi(i,g) = flx(i,g)/flxg(g)
c                     where flxg(g) is [sum over i of (flx(i,g)*Vi)]
c                     and Vi is the nodal volume in the radial model
c   ***** NOTE: |isyn| = 2 has not been tested in this version of SYN2D *****
c   norm = normalization option
c      0 -- no further normalization is needed (note that xmult and ymult can
c           be used to pre-normalize the individual radial and axial profiles
c      1 -- normalize the 2-D flux profile at a point given by i = iin and
```

```
c              j = jjn over the energy range defined by the ewtg function given
c              in the 6** array to the value of xynorm.  This option allows
c              one to normalize the flux at a given space point over some energy
c              range to some desired value.  The distribution is normalized by
c                    alpha = xynorm/[sum over g ewtg(g)*phi(iin,jjn,g)]
c              such that
c                    phinew(i,j,g) = alpha*phiold(i,j,g)
c
c
c   fill array with zeros
c
c
c  3** Array (3 entries)
c
c   xmult = factor for all x-directed (radial) fluxes (default = 1.0)
c   ymult = factor for all y-directed (axial) fluxes (default = 1.0)
c   xynorm = global normalization factor at mesh iin,jjn (default to 1.0)
c
c  END BLOCK #1  (terminate with a 't')
c
c
c FIDAS INPUT BLOCK #2  (primary input data for problem)
c
c  2** Array (jm+1 entries)
c   ymb(jm+1) - second dimension y-directed (axial) mesh boundaries
c
c  4** Array (im+1 entries)
c   xmb(im+1) - first dimension x-directed (radial) mesh boundaries
c
c  6** Array (igm entries)
c   ewtg(igm) -- weight function that defines the energy range of
c                interest (usually either 0.0 or 1.0 to identify
c                the groups of interest  (only needed for norm = 1)
c
c
c  END BLOCK #2  (terminate with a 't')
c
c ****************************************************************
c
```

SYN2D Input Notes

The input to SYN2D is quite straightforward and self-explanatory. Obviously, two 1-D flux profiles must be available. The format for the input fluxes is set via the **iflx1** flag (both files must have the same format) and a similar switch, **iflx2**, sets the output format. Since the output 2-D flux file will probably be used by PROCESS or ACTIV (or some other post processing code) for additional analyses, only the ascii or binary scalar flux formats are available for output.

The **xmult** and **ymult** factors are used to individually normalize the 1-D radial and axial profiles. If proper normalization has already been done as part of the DORT input, then these quantities should be set to unity. If the 1-D DORT models are not normalized, then **xmult** and **ymult** allow this capability within SYN2D. For example, for the 1-D JPDR models, the normalization was done in SYN2D, where the normalization factors were computed as follows:

Radial Model

$$\text{xmult} = \frac{P_{model}}{P_{total}} = \frac{1}{H_{core}} = \frac{1}{146.7} = 6.817e - 3$$

Axial Model

$$\text{ymult} = \frac{P_{model}}{P_{total}} = \frac{(1)^2}{\pi(R_{core})^2} = \frac{1}{\pi R_{core}^2} = \frac{1}{\pi(64.79)^2} = 7.583e - 5$$

where H_{core} and R_{core} are the height and effective radius in cm of the JPDR active core region. These factors are only approximate, of course, since they assume that the power density is constant in the transverse (untreated) directions. This approach, however, is standard for treating models of lower dimensionality (where P_{model} is the power generated in the portion of the model treated and P_{total} is the total reactor power).

Some 1-D Versus 2-D Comparisons

As part of the testing process, several SYN2D runs were made and the resultant synthesized flux profiles were compared directly to the reference 2-D RZ JPDR fluxes. To facilitate these comparisons, the 47-group fluxes were collapsed to three broad groups:

     fast   -- above 0.111 MeV including groups 1 – 26,

     epithermal   -- 0.414 eV to 0.111 MeV including groups 27 – 45,

     thermal   -- below 0.414 eV including groups 46 and 47 of the 47-group structure.

In addition, another small Fortran program was written to read the 2-D synthesized fluxes and the fluxes from the full 2-D model, take their ratio, and write these in a standard format (a CCCC RTFLUX file) that can be processed by some UMass-Lowell in-house plotting codes.

Summary results for several sequences are described below:

Sequence #1 (S1)

This case used the SYN2D global normalization option (**norm** = 1) with **isyn** = 1. The thermal flux from the JPDR RZ model was 2.772e+11 at core center and z = 360 cm (**jjn** = 134). Thus, **xynorm** was set to 2.772e+11 and **xmult** = **ymult** = 1.0. Also, the energy-dependent weight function selected only groups 46 and 47 (i.e. the thermal range in the 47-group library).

The 3-group flux ratios in the radial direction at z = 360 cm and in the axial direction at the core shroud (r = 80 cm) and PV liner (r = 104 cm) are shown in Figs. 1-3. If the 2-D synthesized fluxes gave the same result as the full 2-D model, all the curves would be flat at the 1.0 mark. However, this is clearly not the case, and significant deviation from unity is apparent.

Since Sequence S1 normalizes the thermal flux to a known value from the 2-D model, the thermal flux ratio is unity at the core center in Fig. 1. Also, as seen in all three figures, the flux ratios for each of the three broad groups remain near unity throughout the active core region. Outside the core region, however, large variations are observed in both the radial and axial directions. In this particular case, the ex-core fast and epithermal fluxes tend to be seriously under-predicted, while the thermal flux ratios are very high outside the core region. In some locations, the 2-D synthesized fluxes are more than a factor of 5 higher and/or lower than those from the full 2-D JPDR model in DORT. This level of error is clearly unacceptable for rigorous activation analysis studies and, even for preliminary studies where a factor of 2-3 uncertainty might be tolerable, the 1-D modeling approach appears questionable.

To help visualize the problem areas for the whole geometry, a series of 2-D images were developed that color code the high to low values for the 3-group flux ratios. Figures 4-6 show these qualitative results for the fast, epithermal, and thermal flux ratios. Each figure has two plots -- the top figure limits the ratios to a factor of 5 (0.2 < ratio < 5.0) and the lower plot sets the ratio limit to a factor of 2 (0.5 < ratio < 2). With these qualitative ratio maps, it is easy to see where the 1-D model either over-predicts or under-predicts the full 2-D fluxes by a factor of 5 or more (upper plots) or by a factor of 2 or more (lower plots). The obvious conclusion here is that, outside the core region, the 1-D models simply cannot be used with any confidence.
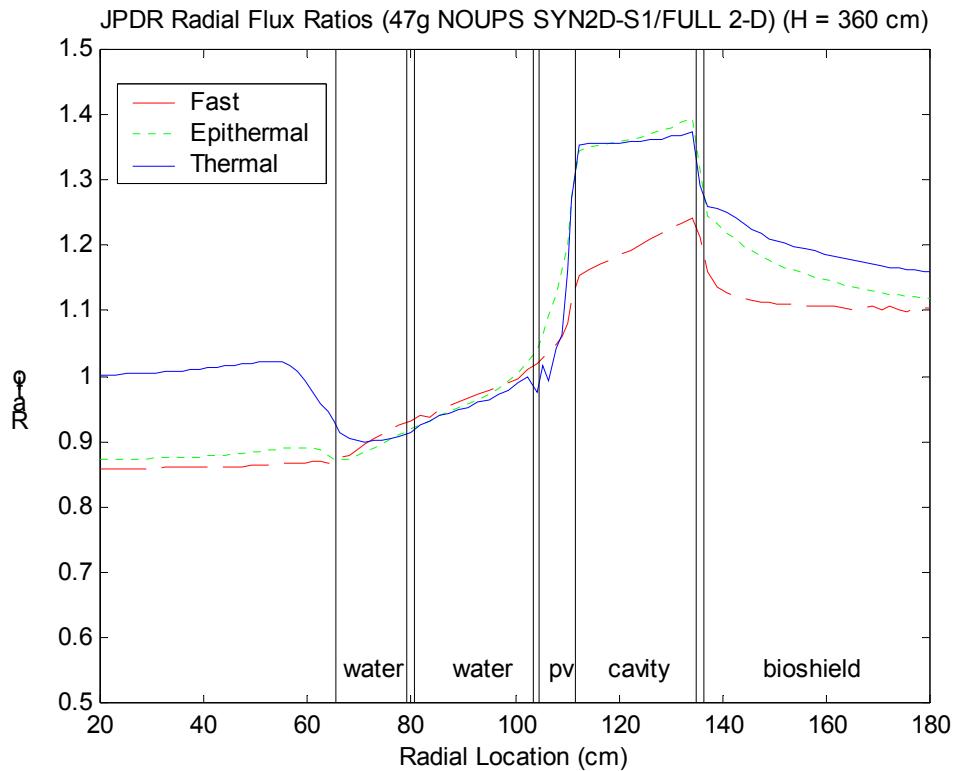

Fig. 1   Radial flux ratios at H = 360 cm for the JPDR RZ model (S1 sequence).
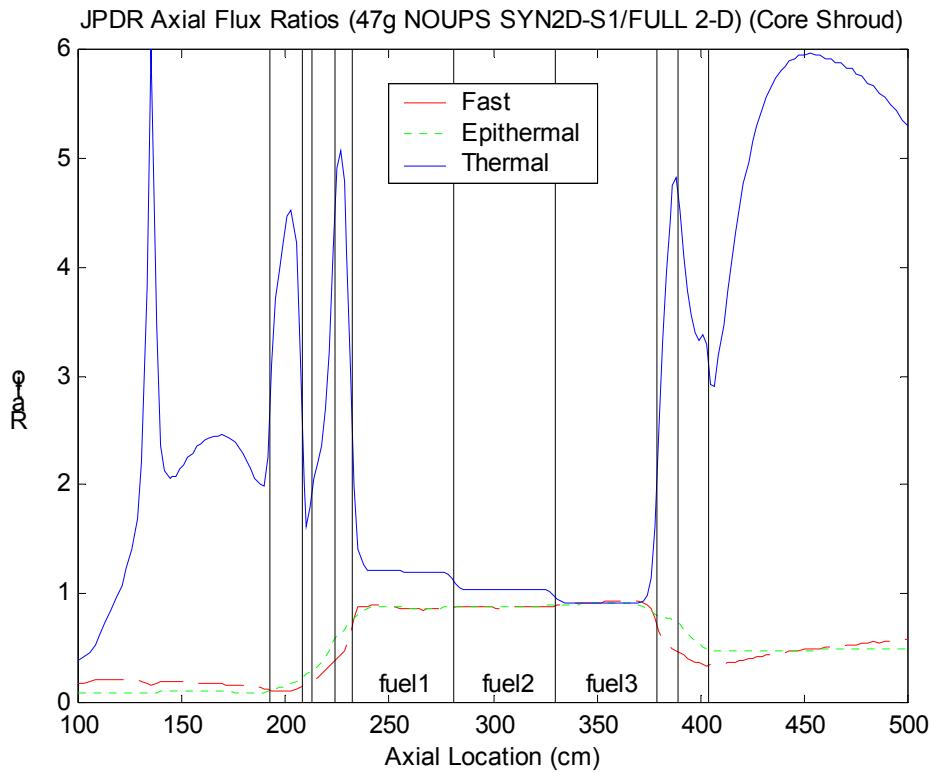
Fig. 2 Axial flux ratios along the core shroud for the JPDR RZ model (S1 sequence).
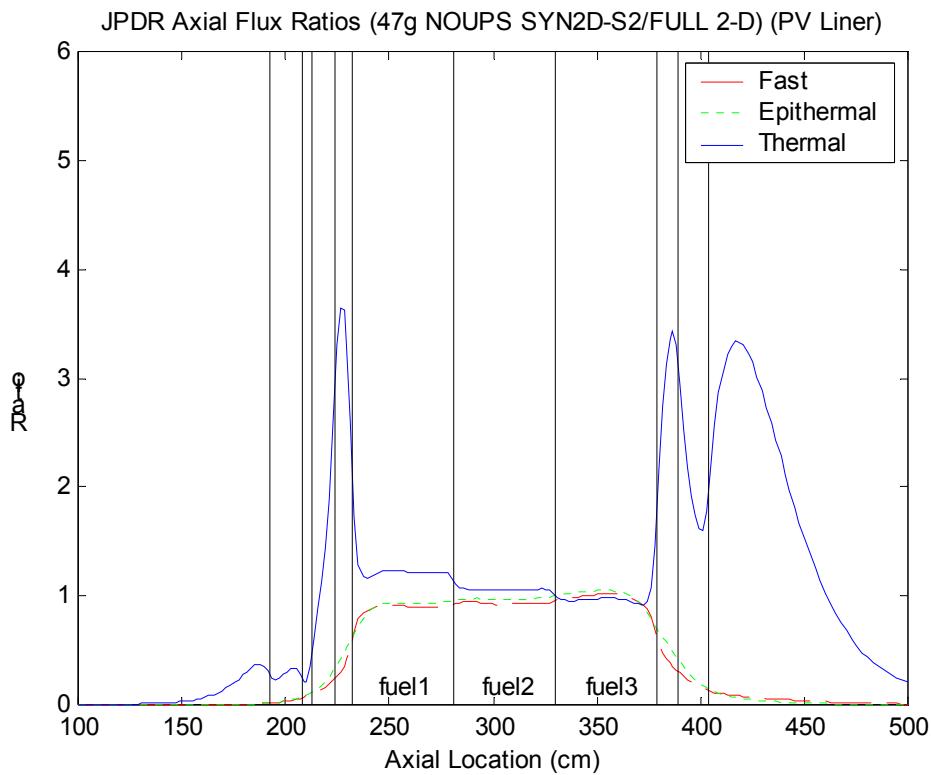

Fig. 3 Axial flux ratios along the PV liner for the JPDR RZ model (S1 sequence).

Fast Flux Ratios (SYN2D-S1/DORT 2D) for JPDR RZ Model

Fast Flux Ratios (SYN2D-S1/DORT 2D) for JPDR RZ Model
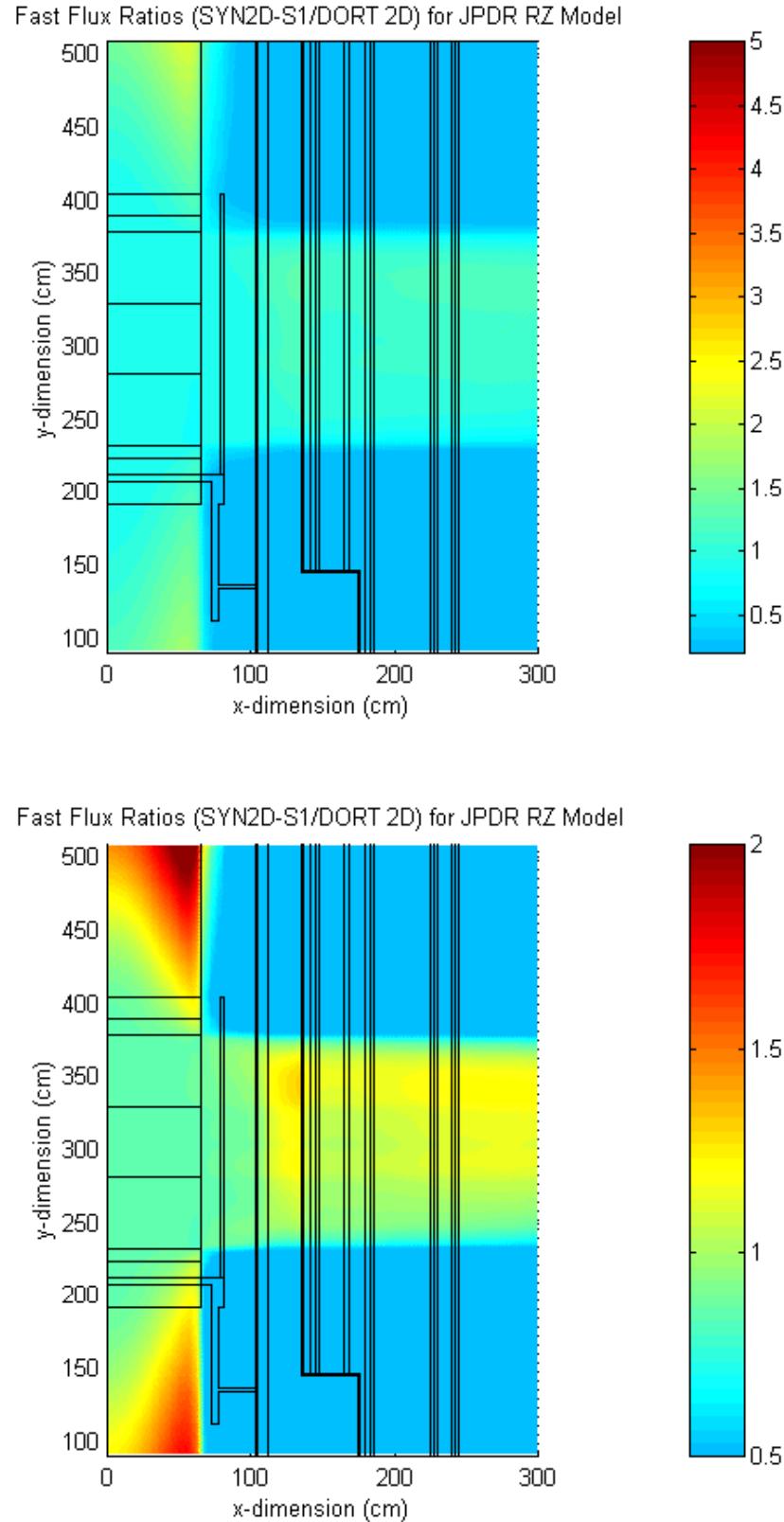
Fig. 4 Qualitative view of the fast flux ratios for the JPDR RZ model (S1 sequence).

Epithermal Flux Ratios (SYN2D-S1/DORT 2D) for JPDR RZ Model

Epithermal Flux Ratios (SYN2D-S1/DORT 2D) for JPDR RZ Model
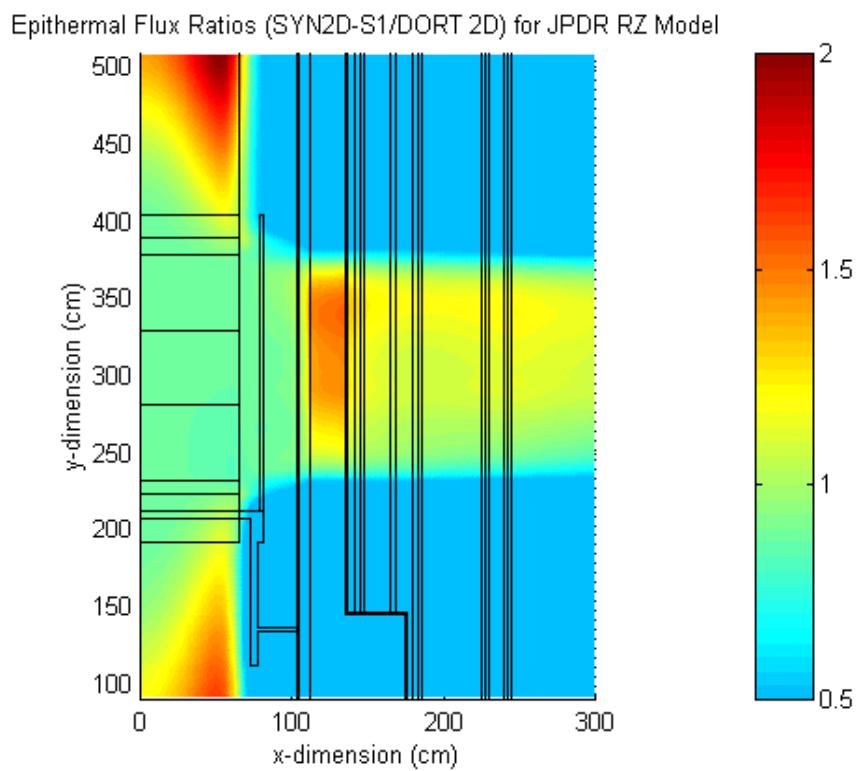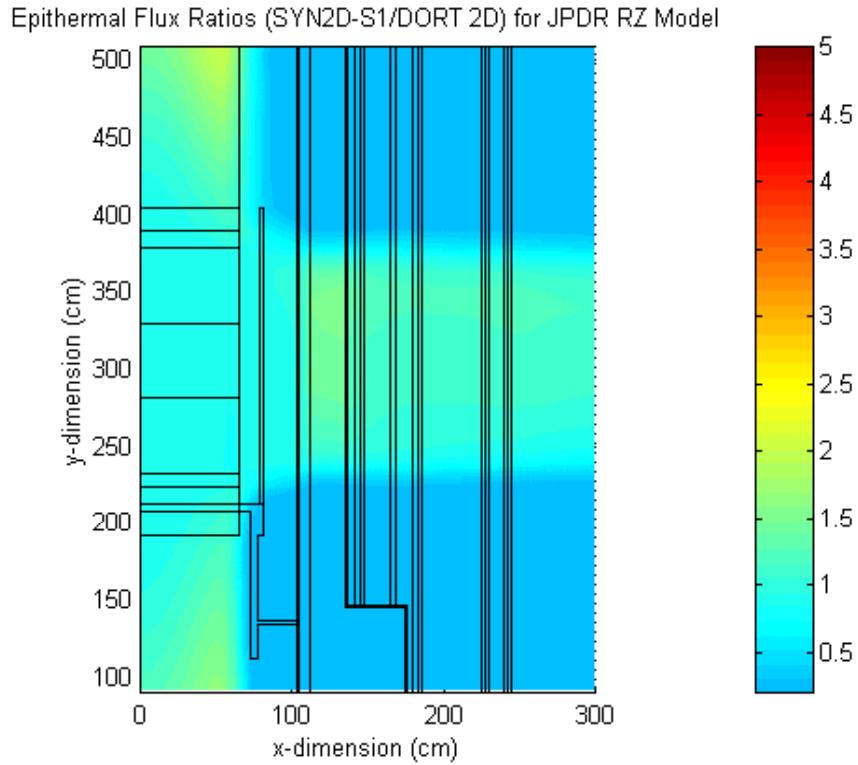
Fig. 5 Qualitative view of the epithermal flux ratios for the JPDR RZ model (S1 sequence).

Thermal Flux Ratios (SYN2D-S1/DORT 2D) for JPDR RZ Model

Thermal Flux Ratios (SYN2D-S1/DORT 2D) for JPDR RZ Model
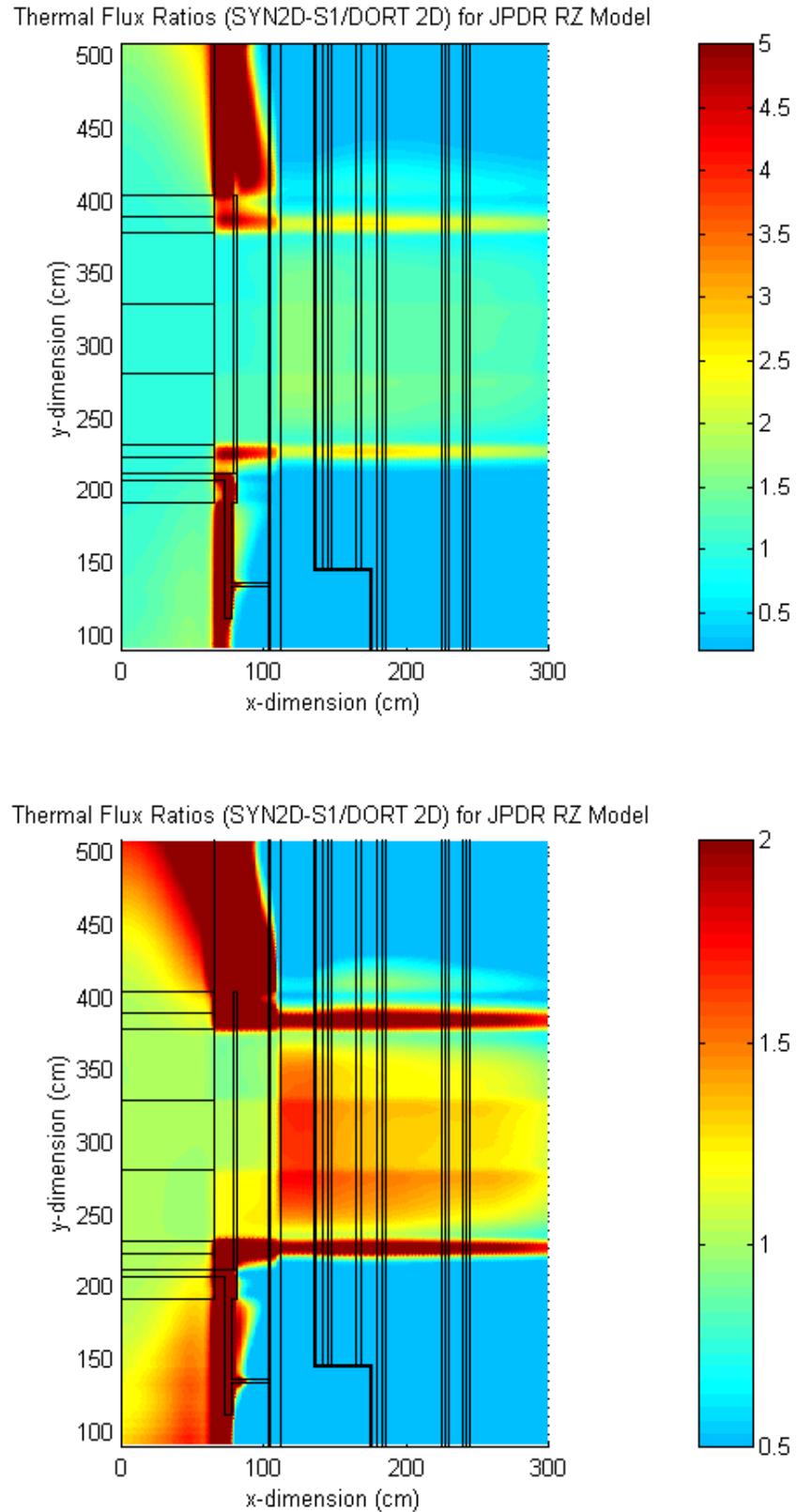
Fig. 6 Qualitative view of the thermal flux ratios for the JPDR RZ model (S1 sequence).

Sequence #2 (S2)

This case, with **isyn** = 1, used individual normalizations for the radial and axial 1-D flux profiles (**xmult** = 6.817e-3 and **ymult** = 7.583e-5). This represents the normal "predictive" mode of operation when neither the full 2-D calculation nor experimental data are available. The resultant ratio plots (see Figs. 7-9) are qualitatively similar to the S1 case, with similar significant deviation from unity in regions outside the active core. There are some subtle differences (S2 versus S1) within the core regions, with slightly better fast and epithermal flux ratios and slightly larger thermal flux ratios for the S2 case. However, these in-core differences are overshadowed by the significant ex-core discrepancies, making the choice of normalization relatively insignificant (for ex-core activation studies).

Sequence #3 (S3)

This case, with **isyn** = -1, is similar to the S2 case but the 1-D radial profile is now used as the shape function. Again, the selected 1-D ratio plots given in Figs. 10-12 show similar qualitative results as discussed previously for the S1 and S2 cases. The in-core results actually appear to be somewhat better, but the ex-core flux ratios still show significant variation above and below unity. Thus, for ex-core activation analysis, this option does not offer any real benefit over the other SYN2D synthesis options.
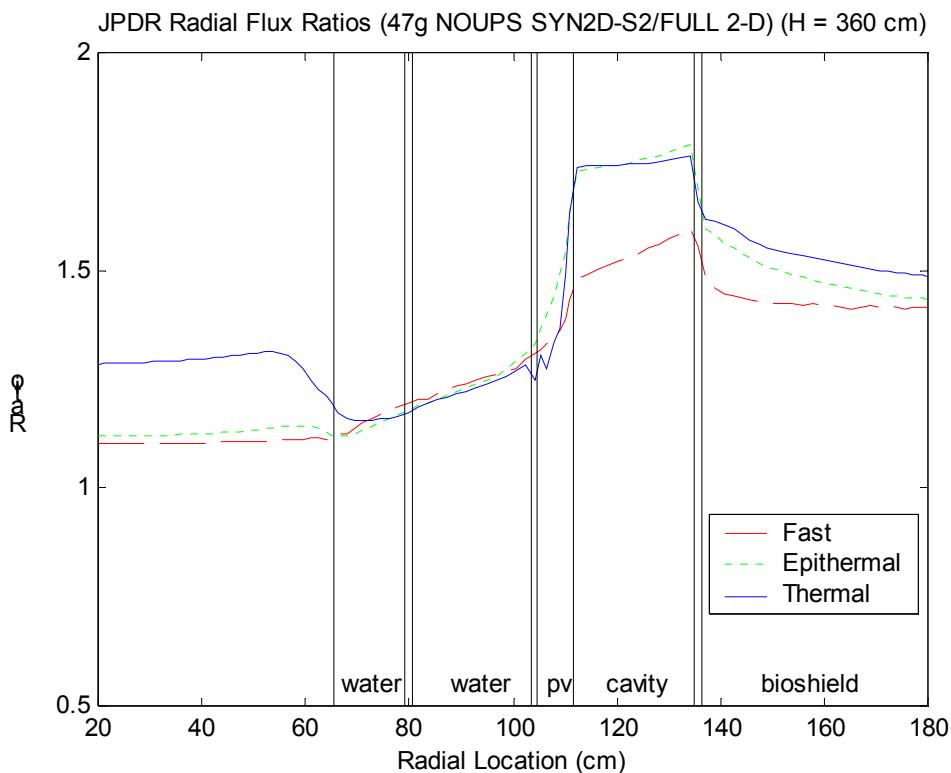

**Fig. 7 Radial flux ratios at H = 360 cm for the JPDR RZ model (S2 sequence).**
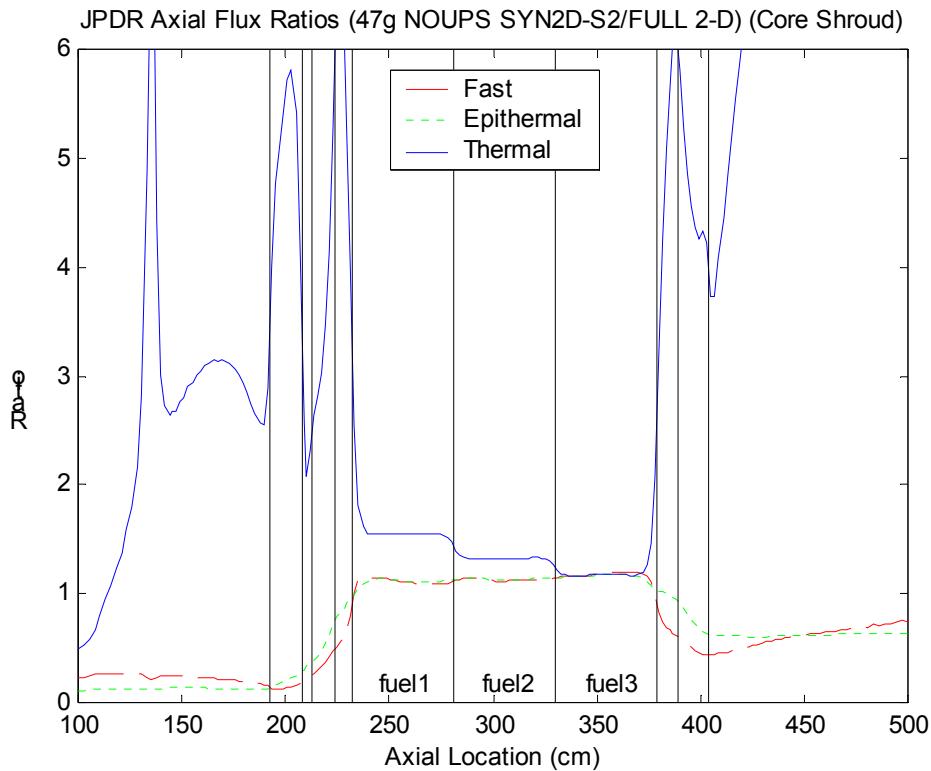
JPDR Axial Flux Ratios (47g NOUPS SYN2D-S2/FULL 2-D) (Core Shroud)

Fig. 8 Axial flux ratios along the core shroud for the JPDR RZ model (S2 sequence).

JPDR Axial Flux Ratios (47g NOUPS SYN2D-S2/FULL 2-D) (PV Liner)
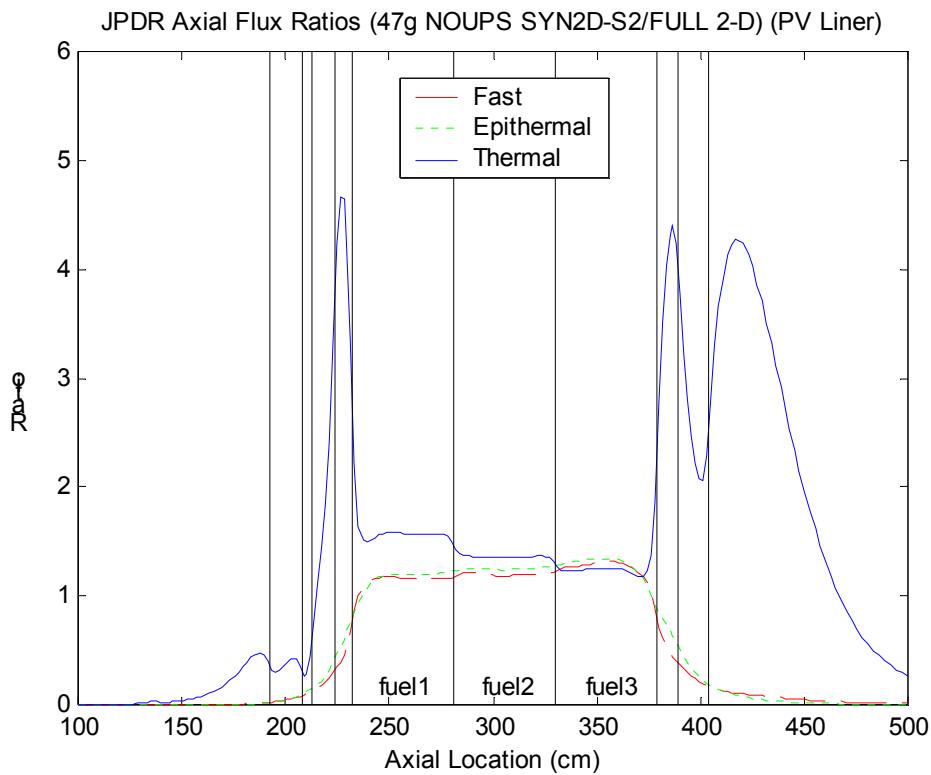
**Fig. 9 Axial flux ratios along the PV liner for the JPDR RZ model (S2 sequence).**
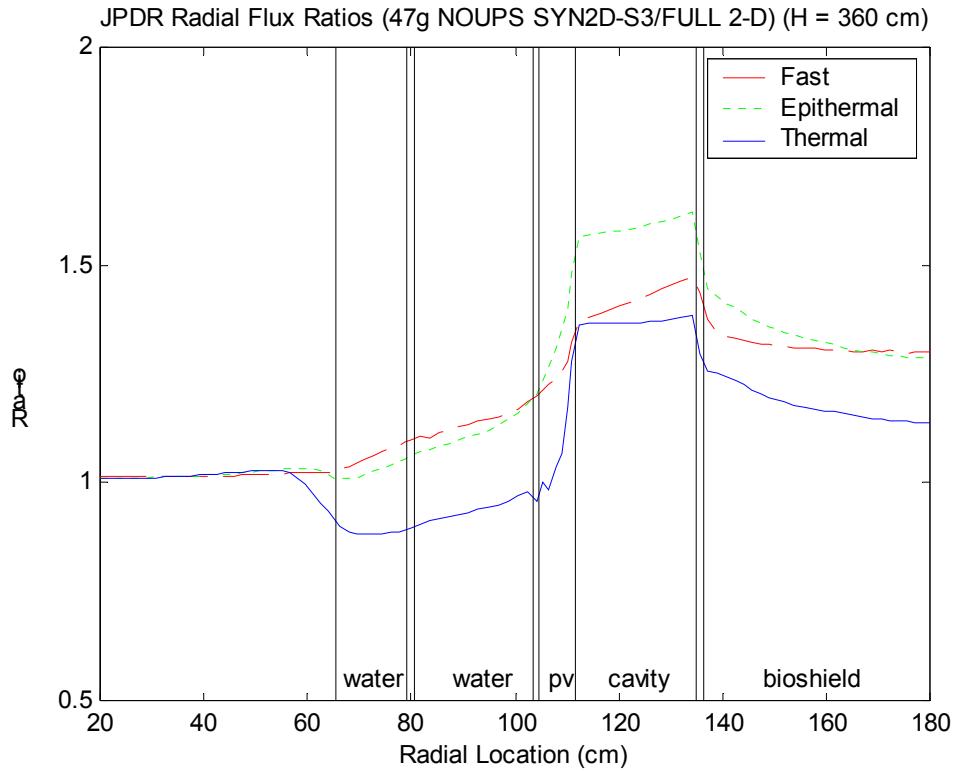
**Fig. 10 Radial flux ratios at H = 360 cm for the JPDR RZ model (S3 sequence).**
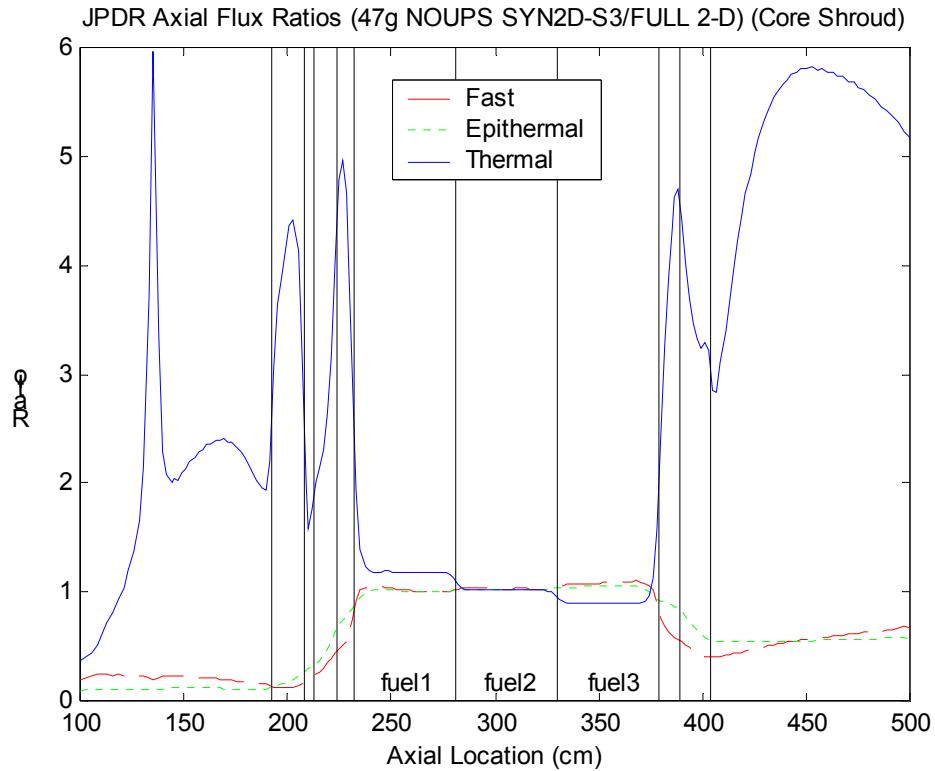
**Fig. 11 Axial flux ratios along the core shroud for the JPDR RZ model (S3 sequence).**
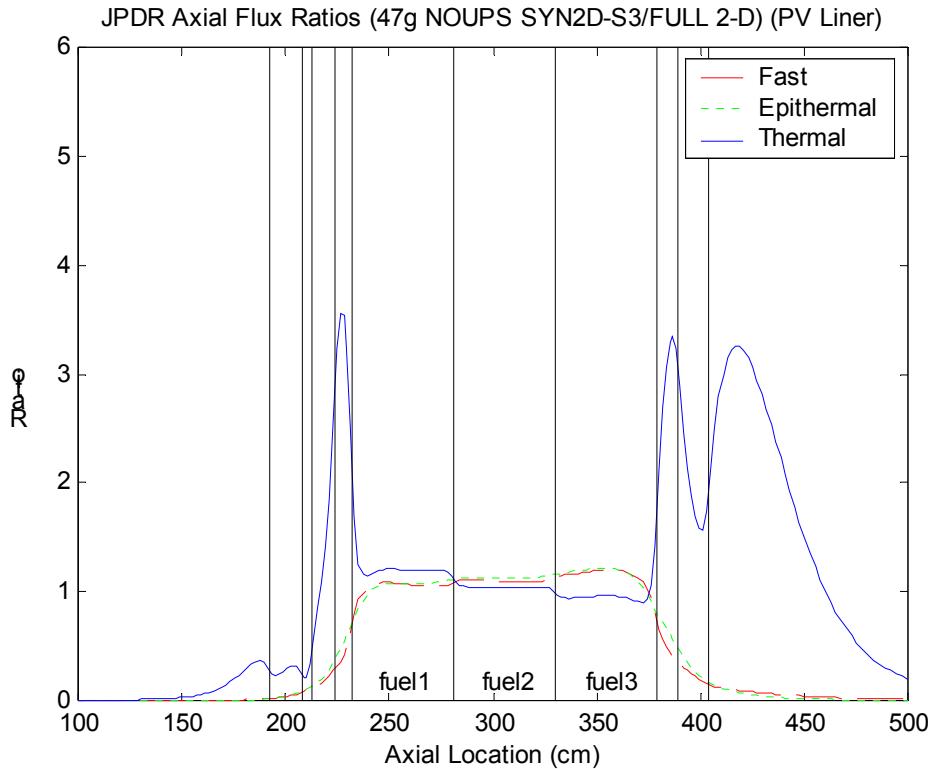
Fig. 12 Axial flux ratios along the PV liner for the JPDR RZ model (S3 sequence).

Summary Conclusions/Recommendations

If one is interested in in-core activation, then the subtle differences between the SYN2D S1, S2, and S3 cases become important. However, the interest here is in the activation of ex-core materials. Thus, the various options within SYN2D make little difference, since all the ex-core results have equally large uncertainty. In all cases, the ex-core flux ratios showed significant deviation from unity -- indicating that some very large errors are possible with the 1-D modeling methodology. Thus, this brief study has indeed estimated the errors that can be expected using a 1-D approximation and, because of the large potential errors (factors of 2 to 5 or larger in many locations of interest), there is serious doubt about the usefulness of the 1-D method for routine ex-core activation analyses. This work suggests strongly that 2-D computational models be used to estimate the neutron flux environment for ex-core neutron activation studies. A 2-D modeling methodology should be adopted as part of the standard computational procedure for all ex-core activation analyses -- since the 1-D approach simply introduces too much uncertainty into the prediction of the ex-core neutron flux.