January 2011 Progress Report on
MCNP Modeling for the UMLRR

Dr. John R. White and Russell Gocht

Chemical and Nuclear Engineering Department
University of Massachusetts Lowell
Lowell, MA 01854

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Introduction/Summary

The goal of this project is to develop and validate a detailed MCNP model of the UMass-Lowell Research Reactor (UMLRR) to support the analysis of subsequent experiments within the facility. This is the second Progress Report in a series of reports that will fully document the development of the computational model and provide some summary results of the model validation process. The previous Progress Report (Ref. 1) gave an overview description of the UMLRR geometry and core layout and then briefly described, via a set of 2-D geometry figures from the MCNP Visual Editor, the basic MCNP representation of the UMLRR that was available at the time of that report (Nov. 2010). At that time, only the in-core geometry was complete and, because of this, there were no computational results to discuss. Thus, the first report focused on only the modeling aspects of the grid plate, core box, and all the in-core elements (fuel assemblies, radiation baskets, graphite reflectors, control blades, etc.) associated with the M-1-3 configuration within the UMLRR.

Since Nov. 2010, we have added a reasonable representation of the ex-core structures (lead shield, thermal column extension, beam tubes, and the discharge header and exit coolant duct) to the core model, and the purpose of this report is to highlight the construction of these geometries in MCNP and to provide some preliminary reactivity-related results for the current M-1-3 model.

The M-1-3 Model (with both in-core and ex-core structures)

As discussed in Ref. 1, the MCNP in-core geometry setup made extensive use of the macrobody specification within MCNP (especially the RPP → rectangular parallelepiped and RCC → right circular cylinder bodies). With these geometry units, we were able to construct the various cells and universes needed to develop the complete in-core model without the use of the union and complement operators and without any specific lattice structures (avoiding the use of unions and lattices was requested by the project sponsor). This same procedure was continued while building the needed ex-core structures, including the lead shield (u = 35) and the thermal column extension (u = 36) on the right side of the core (+x direction), the 8″ and two 6″ beam tubes on opposite sides of the core (u = 40-45) (in the + and – y directions), the discharge header/lower plenum (u = 47) below the core, and finally the coolant discharge duct that comes up along the left side of the core (u = 48) (i.e. on the –x side). These units represent reasonable approximations to the as-built structures and they should give the proper core-reflector boundary conditions on all of the core faces (these were missing in our earlier MCNP model of the UMLRR, where only a pure water reflector was modeled on each core surface).

As before, for the current Progress Report, we will simply provide some overview documentation of the MCNP geometry via a set of 2-D geometry figures generated by the MCNP Visual Editor. These drawings, along with some summary descriptive comments, are given in Figs. 1 – 6, and they provide a pretty good summary of the currently available MCNP model. Note that the in-core components that were highlighted in the previous Progress Report (Ref. 1) have not changed, and only a limited discussion of these structures is given here. Instead, Figs. 1 – 6 try to emphasize the new ex-core elements that have been added to the model since the last report. In particular, careful study of these geometry sketches shows that all of the key ex-core features associated with the UMLRR M-1-3 configuration have been treated, and that we indeed have a fairly rigorous representation of the real physical system. A number of simplifying assumptions were made in generating these structures, but they still give a pretty good picture of the real facility -- and this model should be able to reproduce measured results with fair accuracy (see some preliminary calculated vs. measured results below).

Movement of the Control and Regulating Blades

Much of the geometry discussed above will remain fixed for most of our subsequent MCNP analyses except, of course, for the position of the four large control blades and regulating blade.

For the four control blades, the large 52″ physical length of the blades makes it relatively easy to adjust the axial withdrawal level for these control elements. In particular, since the upper level of the control portion of the blades is already so far from the core, this level is kept fixed as the blades are moved outward. Thus, in the model, only the lower limit of the blade is adjusted when one of the four large control blades is moved.

Considering Blade 4, for example, the surface cards used to describe the portion of the blade within the core box are listed below, where we note that only the lower z-level for surfaces 118 and 119 are changed when the blade is moved.

```
c
c    surface cards -- Blade #4 (15.3" withdrawn -- affects only zstart for 118 & 119)
116  rpp  11.6585  46.6345    7.9693  10.4712   -0.0001  76.2001  $ outer shroud
117  rpp  12.38298 39.84673   8.26775 10.17275   1.2700  76.2001  $ inner shroud
118  rpp  12.58936 39.64036   8.7440   9.6965    43.942   76.2001  $ outer blade
119  rpp  12.74176 39.48796   8.8964   9.5441    44.0944  76.2001  $ inner blade
120  rpp  11.6586  46.6344    7.7724  10.6681    0.00     76.200   $ Blade #4 UNIT CELL
```

Note that a blade that is fully inserted, at 15.3 inches out, and fully withdrawn (26″ out) would have starting z dimensions as follows (everything else remains unchanged):

		Surface 118 (0.06″ thick clad)	Surface 119 (blade)
fully inserted:	z = (2 + 0)*2.54 =	5.080 cm	5.2324 cm
15.3″ withdrawn:	z = (2 + 15.3)*2.54 =	43.942 cm	44.0944 cm
fully withdrawn:	z = (2 + 26)*2.54 =	71.120 cm	71.2724 cm

where the 2″ bias is needed since z = 0 in the model is 2″ below the fully inserted position of the blade.

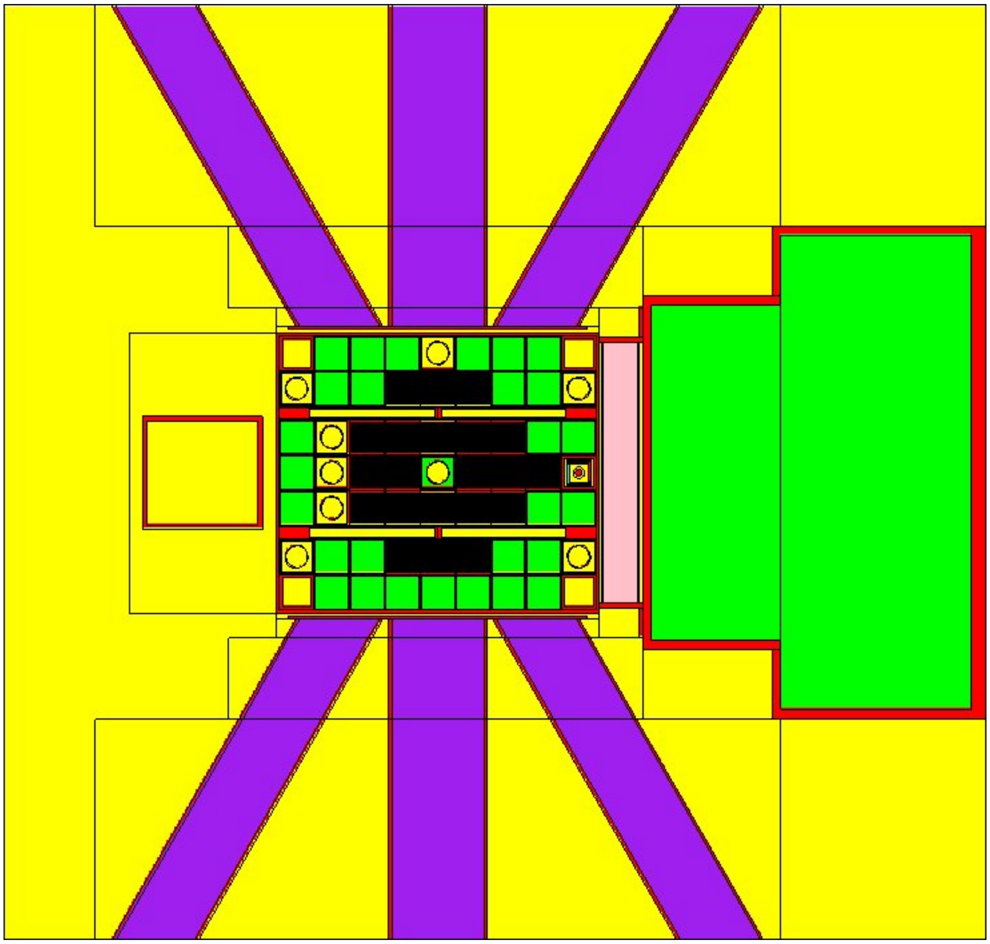


Fig. 1 Full XY view of UMLRR M-1-3 core model (z = 38.1 cm).

Comments:

This figure represents an XY cut near the axial centerline of the active fuel region for the UMLRR M-1-3 core configuration. One can easily see many of the new ex-core elements that have been included in the current MCNP model, including the lead shield and thermal column extension (i.e. the light pink Pb region and large green graphite blocks, respectively, on the right side of the figure), the six individual beam tubes with three ports each on both the +y and –y sides of the core, and the rectangular discharge duct walls on the left side of the model. Note that the two perpendicular beam tubes along the core centerline have an 8″ inside diameter and the four angled ports are 6″ inside diameter aluminum tubes.

Clearly, the core region is simply too small in this view to adequately give the resolution needed to visualize any real detail. However, as noted above, the in-core configuration is unchanged from the earlier model (except possibly for the axial location of the control elements), so one can see the appropriate drawings in Ref. 1 for more details in the in-core region of the complete model.

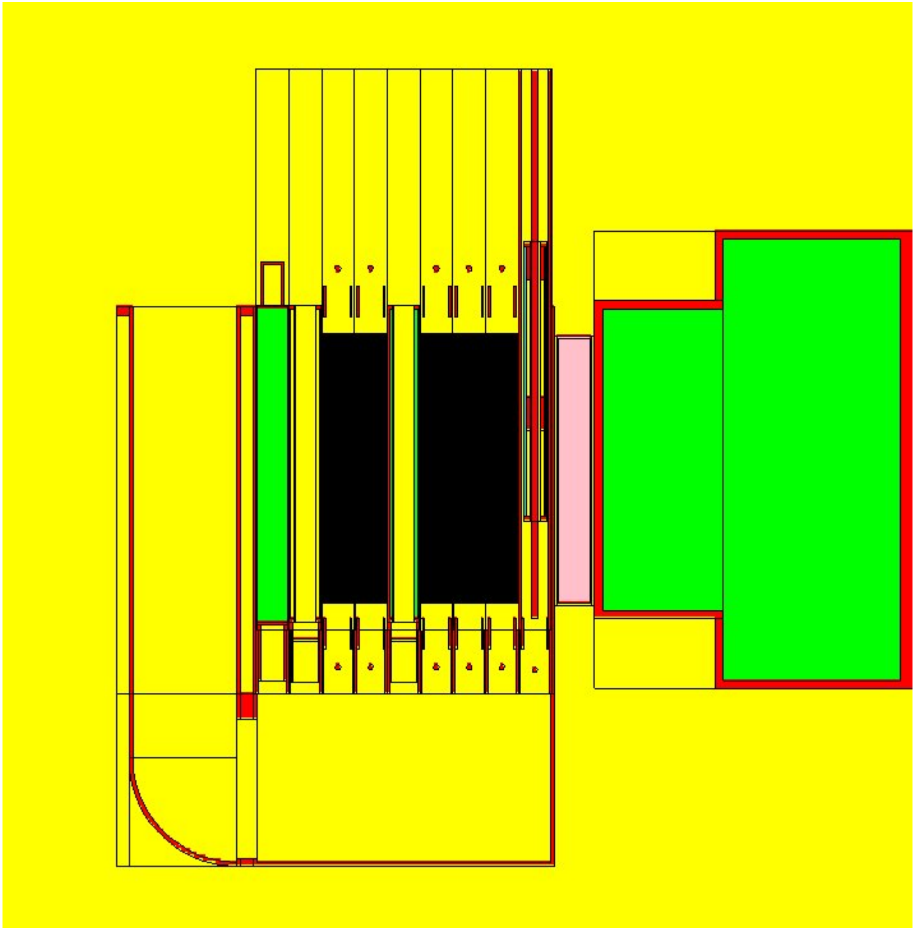


Fig. 2 Full XZ view of the M-1-3 configuration near the core centerline (y = 22.2 cm).

Comments:

This figure highlights the axial direction with an XZ cut near the centerline of the core (in the y direction). From left to right, one sees the discharge duct, a thin core box, a series of in-core elements (graphite reflector, radiation basket, two fuel elements, the central flux trap assembly, three more fuel elements, and the regulating blade), the other side of the core box, and finally the lead shield and thermal column extension. Below the core and grid plate regions are the lower plenum (also referred to as the discharge header) and the exit to the rectangular discharge duct.

Note that the discharge duct was only modeled up to the top of the core box where, in practice, it turns into the paper (+y direction) for a short distance and then continues along the +y side of the core axially up the core support structure to exit the pool. However, these structures are so far removed from the core region that they have negligible effect on the core neutron balance and, since we currently have no real interest in computing the radiation field in these regions, the duct was discontinued at the 76.2 cm mark (30′′ above the grid plate).

Also note that, in this view, the regulating blade is positioned at 8 inches withdrawn relative to the fully inserted level (really 10′′ out relative to z = 0). This location, along with the other four control blades at 15.3′′ withdrawn, was the actual critical blade configuration for the initial M-1-3 core.

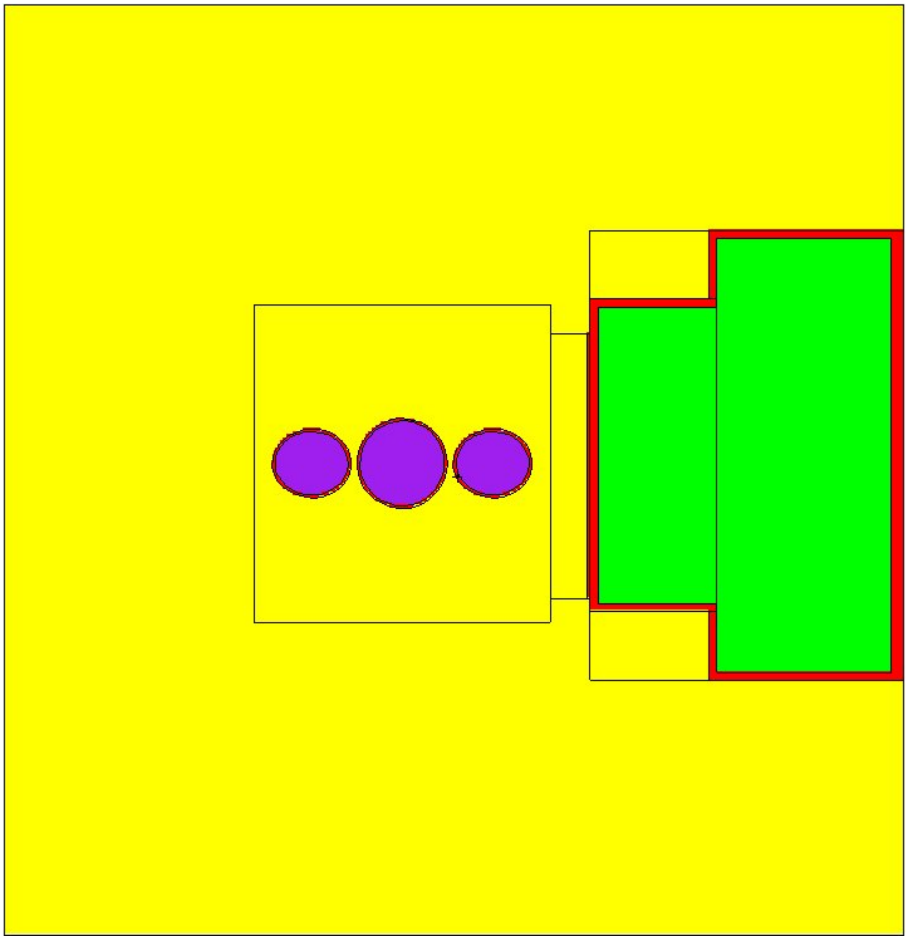


Fig. 3 Another XZ view just outside the core box on the –y side of the core (y = –10 cm).

Comments:

This diagram gives another XZ view at y = –10 cm -- which represents a cut just outside the core box region on the lower side of the core as seen in Fig. 1. The goal here was simply to highlight the geometry of the beam tubes as one looks down the central tube in the direction of the core. Note also that, in the reference models, all the tubes contain air at standard temperature and pressure (i.e. the blue/purple region inside the tubes).

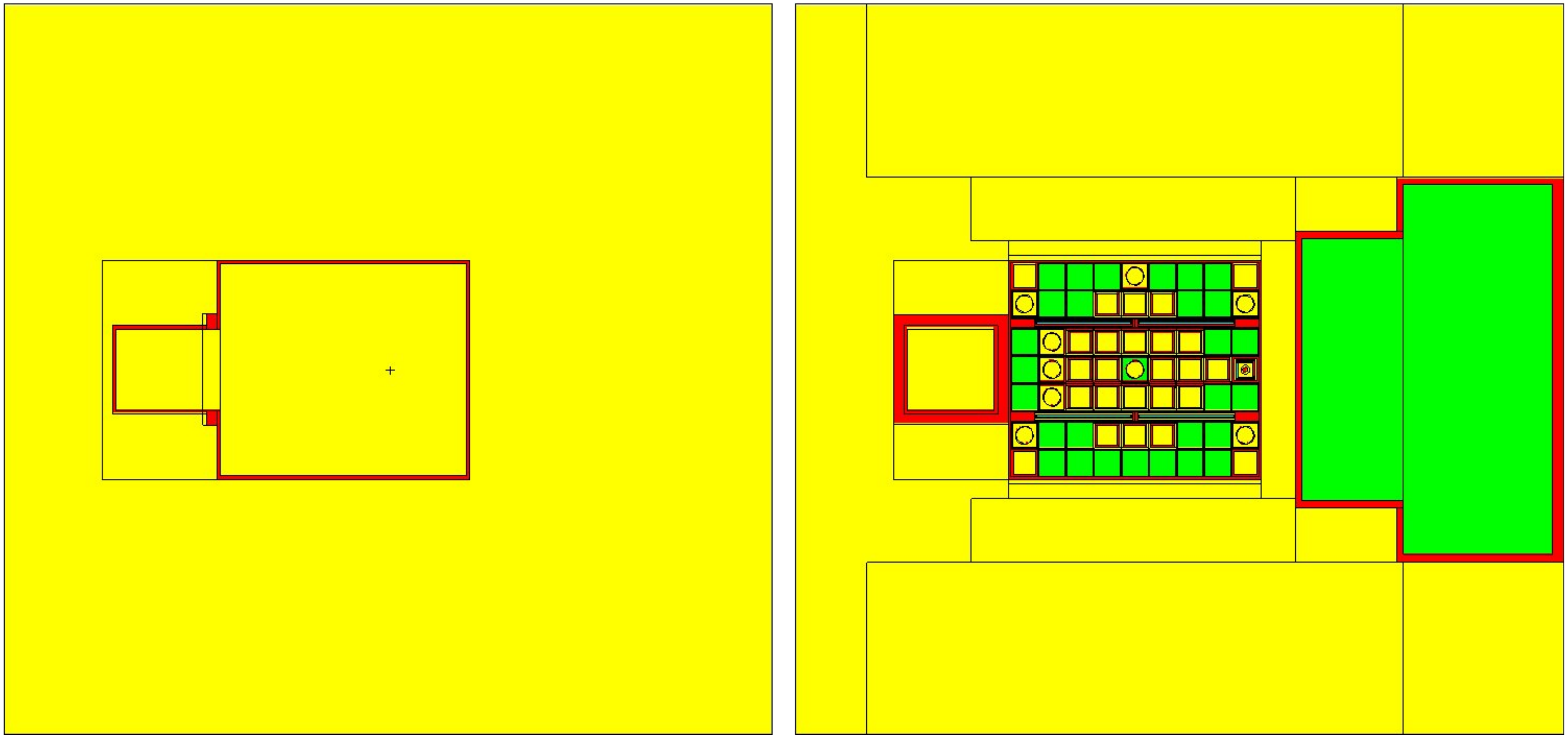


Fig. 4 Two more XY views just below (left) and above (right) the active core region.

Comments:

These figures highlight the discharge header and duct geometries in the XY plane just below and just above the core regions. In particular, the left figure represents the lower plenum and discharge duct at z = –25 cm (which is a short distance below the grid plate region). The right figure, in contrast, shows a cut at z = 75 cm which is just below the top of the core box. In this latter view, one can see the upper flange on the discharge duct where it connects to the piece that turns in the +y direction (but, as noted above, this latter piece is not modeled). Also, in the right view, one can see several in-core details, such as the top of the graphite reflector elements, a portion of the end boxes on the fuel elements, the four large control blades, etc., etc. -- but, because of the full extent shown for the complete model, the resolution for the in-core region is not great (see Ref. 1 for further in-core details).

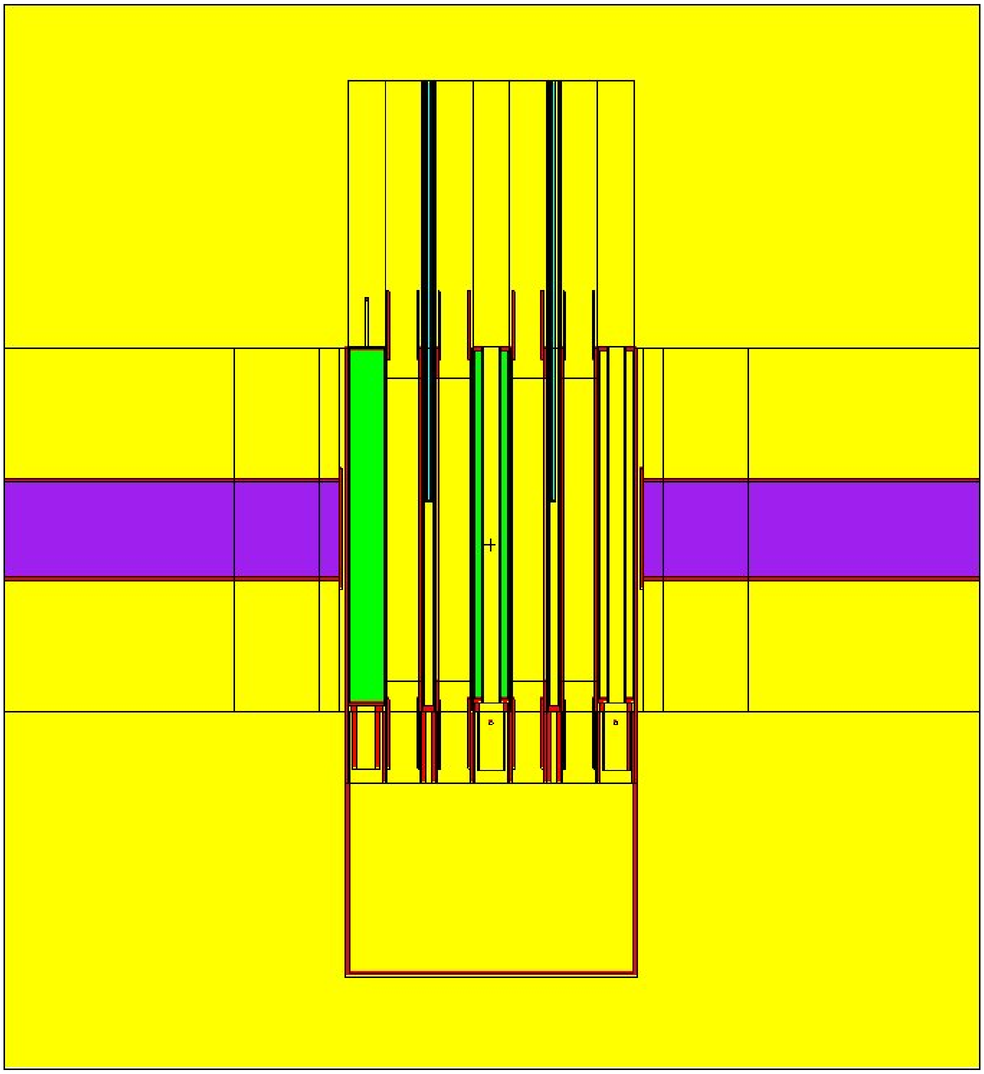


Fig. 5 Full YZ view of the complete UMLRR M-1-3 core model (x = 10 cm).

Comments:

This figure represents a YZ cut just to the left of core center in the x-direction. This location was chosen to highlight the axial position of the control blades (specifically Blades 1 and 2) and to include as many of the other assembly types as possible. In particular, from left to right, this view includes the 8″ beam tube on the –y side of the core, a graphite reflector element, a full fuel element, a partial fuel assembly, the central flux trap, another sequence of partial and full fuel elements, the radiation basket that served as the startup source holder, and finally, another 8″ beam tube on the +y side of the core. Note, however, as noted in Ref. 1, one cannot distinguish between the full and partial assemblies because the precise x location was chosen to correspond to a water channel between two fuel plates (see next figure for a traverse directly through the fuel meat).

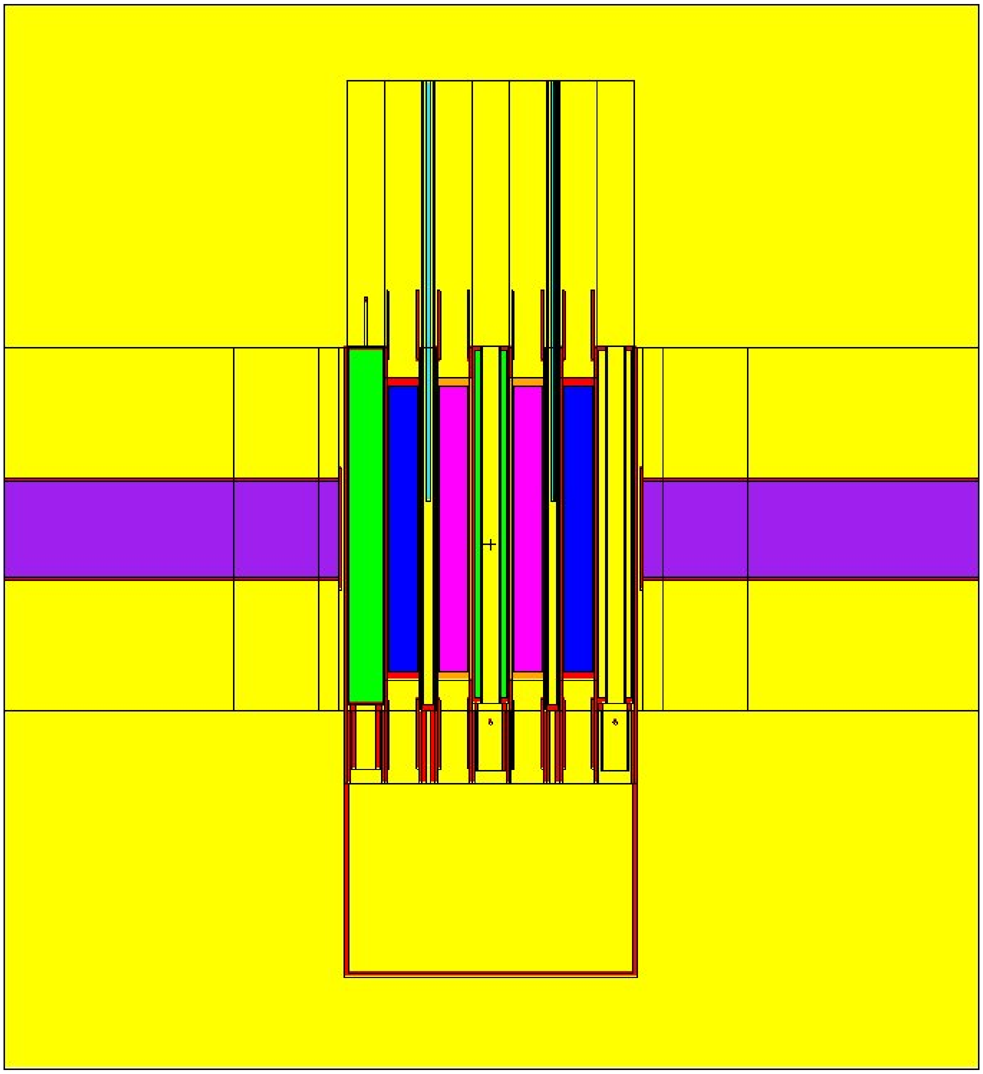


Fig. 6 Full YZ view of the complete UMLRR M-1-3 core model (x = 10.17 cm).

Comments:

This figure is nearly identical to the previous YZ cut, with the exception that this is taken at a location 0.17 cm to the right of the previous one. This specific x location gives a cut directly through the center of one of the fuel plates. Therefore, in this view, it is indeed easy to see the difference between a full fuel plate (the dark blue color) and partial fuel plate (the pinkish color). Thus, this diagram, in addition to all the other features that it shows, also gives a good view of the fuel plate model used   -- which was one of the key building blocks for this overall MCNP model of the UMLRR LEU core.

Note: Figures 5 and 6 in this report are very similar to Figs. 12 and 13 from Ref. 1, except now we also show the beam tubes (which were not included in the model documented in the earlier report).

Now, for the regulating blade, things are not so simple because the full blade length is only 26″. Thus, when the blade is moved, both the starting and ending axial positions change. In addition, the actual geometry is more complicated to describe than for the large control blade, requiring several more surfaces to fully describe the moveable portion of the regulating blade -- as illustrated with the surface cards given below for the regulating blade withdrawn 8 inches:

```
c
c    surface cards -- moveable portion of Reg Blade at  8.00 inches withdrawn (operational units)
125  rcc  42.74820  22.32670  25.39990   0.00000   0.00000  66.04010  1.27000  $ 1 inch dia hole
126  rcc  42.74820  22.32670   2.54000   0.00000   0.00000 132.00010  0.71437  $ 9/16 inch rod
127  rpp  40.04935  40.68445  19.62785  24.39045  26.67000  90.17000         $ left blade outside
128  rpp  40.15105  40.58285  19.72955  24.28885  26.67000  90.17000         $ left blade inside
129  rpp  40.04935  44.81195  24.39045  25.02555  26.67000  90.17000         $ top blade outside
130  rpp  40.15105  44.71035  24.49205  24.92385  26.67000  90.17000         $ top blade inside
131  rpp  44.81195  45.44705  20.26295  25.02555  26.67000  90.17000         $ right blade outside
132  rpp  44.91355  45.34535  20.36455  24.92385  26.67000  90.17000         $ right blade inside
133  rpp  40.68445  45.44705  19.62785  20.26295  26.67000  90.17000         $ bottom blade outside
134  rpp  40.78605  45.34535  19.72955  20.16135  26.67000  90.17000         $ bottom blade inside
135  rpp  40.04935  45.44705  19.62785  25.02555  90.17000  91.44010         $ top end cap
136  rpp  40.04935  45.44705  19.62785  25.02555  25.39990  26.67000         $ bottom end cap
137  rpp  40.68445  44.81195  20.26295  24.39045  82.55000  90.17000         $ upper inner Al block
138  rpp  40.68445  44.81195  20.26295  24.39045  46.99000  54.61000         $ lower inner Al block
139  rpp  40.68445  44.81195  20.26295  24.39045  26.67000  90.17000         $ full inside volume
140  rpp  40.04945  45.44695  19.62795  25.02545  25.40000  91.44000         $ Reg Blade UNIT CELL
```

Note here that both the starting and ending z-locations for surfaces 127 – 140 will change each time the regulating blade in moved. Thus, to simplify this process and to reduce the chance of making an input error, a short Matlab code (called **regblade.m**) was written to write out this block of surface cards given the desired position of the regulating blade. Therefore, each time a new blade position is desired, the user will only need to run **regblade.m** and cut and paste the code output into the appropriate section of the MCNP input file.

Some Preliminary Reactivity-Related Results

The purpose for first modeling the M-1-3 core is that this configuration represents the startup core for the LEU fueled UMLRR. As such, several reactivity-related parameters and the axial profiles of the thermal flux at several locations were measured during the initial startup tests for the new core. In addition, we have also compared these measured results to 3-D VENTURE models of this beginning-of-life (BOL) configuration (see Refs. 2 and 3). The goal here is to use the available measured data and prior modeling results to help validate the current MCNP model of the UMLRR.

Reference Critical Core k_{eff} Calculation: In particular, to date, we have only calculated and compared a portion of the available information -- focusing first on the computation of k_{eff} for the "critical" core configuration and the evaluation of the blade worth curves and the excess reactivity associated with the initial startup core. For the critical M-1-3 configuration, the four large control blades were banked at 15.3″ withdrawn and the regulating blade was approximately 8″ out (relative to its fully inserted position, where the total blade traverse is 26 inches). Unfortunately, however, both our most recent 3-D VENTURE model and the current detailed MCNP model (both using cross sections based on ENDF/B-VII data) under-predict the core reactivity for this configuration -- by roughly 2.5 %Δk/k for VENTURE (k_{eff} = 0.975) and by 1.5 %Δk/k for MCNP (k_{eff} = 0.985). The cause of this deviation from a critical value of k_{eff} = 1.0 is not known and this is somewhat troublesome, especially for the MCNP model where we can't blame this discrepancy on the cross section processing and spatial homogenization procedures needed for the deterministic VENTURE model.

At present, relative to the under-prediction of the “critical” k_{eff} value, we have only investigated a few ideas -- one related to control blade depletion effects, and another associated with the density of the reactor-grade graphite used within the UMLRR facility. Concerning the possibility of B-10 depletion within the control blades, a quick burnup calculation was made using the 3-D VENTURE model to address this issue. Although the reactor has been in operations for many years with the same original control blades, the total MWD burnup is relatively low since the reactor has a low overall duty cycle and it is often run at lower than nominal power during many training and testing operations. In particular, there was less than 280 MWD of total energy generation in the prior HEU fueled core. To cover this power history and to account for differences between HEU and LEU operation, the LEU core was depleted for 315 MWD and the B-10 depletion at the tip of the control blades (within a zone of height Δz = 3 cm) was observed to be less than 2 a/o. Since the control blades in the UMLRR are large and can be treated essentially as black absorbers, a change in B-10 density of this magnitude should have negligible effect on the computed k_{eff}. Thus, B-10 depletion does not appear to be the cause of the low prediction in the critical k_{eff} value.

Concerning the graphite density, published mass densities for reactor grade graphite vary considerably, from roughly 1.5 – 1.8 g/cm^3, where it should be noted that ρ = 1.6 g/cm^3 has been used as the reference case in all the VENTURE and MCNP models to date. As a sensitivity test, the graphite density for the MCNP M-1-3 model was increased to 1.8 g/cm^3 and this change increased the “critical” k-value to 0.990. Although this value of graphite density is on the high side of the referenced values, we have decided to use this as a new reference, since the reactivity bias is now reduced to about -1.0 %Δk/k.

Blade Worth Predictions: Our overall experience with the current 3-D VENTURE model relative to measured results has been quite good, except for the absolute reactivity bias of -2.5 %Δk/k and the prediction of the regulating blade worth. In particular, most of the reactivity worth computations with the model, such as developing the blade worth curves for each of the large control blades and the computed estimates of the BOL excess reactivity of the fuel (if the blades were fully withdrawn), have been quite reasonable relative to measured data. Thus, as a first test of the new MCNP model, a similar set of simulated blade worth calculations were made.

The summary MCNP results are compared here relative to the measured data and against the 3-D VENTURE results -- as given below in Tables 1 – 3 and Figs. 7 – 9, and in the accompanying notes for the data tables. In particular, the three tables show similar data for the measured results, the VENTURE results, and the MCNP calculations. Similarly, the three figures show example differential and integral blade worth curves for Blade 4 generated with actual measured data and the simulated data from the VENTURE and MCNP models. These summary results show similar overall trends and they clearly give some credibility to the new MCNP model generated as part of this work (see the Notes following each of the subsequent tables for further discussion of the primary results from this set of comparisons…).

Table 1 Measured results from M-1-3 startup core (August 2000).

	Theoretical Model (simple cosine fit)			New Model (3^{rd} order polynomial + cosine fit)		
Blade #	**Total Worth %Δk/k**	**Fit Quality R^2 Value**	**Excess Reactivity %Δk/k**	**Total Worth %Δk/k**	**Fit Quality R^2 Value**	**Excess Reactivity %Δk/k**
Blade 1	2.53	0.90	0.83	2.63	0.98	0.66
Blade 2	2.38	0.78	0.78	2.47	0.90	0.57
Blade 3	3.34	0.89	1.09	3.32	0.96	0.80
Blade 4	3.19	0.83	1.04	3.20	0.91	0.79
Total Worth Blades 1 – 4	11.4	--	3.74	11.6	--	2.82
Regulating Blade	0.28	--	0.23	--	--	--
Total Worth All Blades	11.7	--	3.97	11.9	--	3.05

Table 1 Notes:

The "theoretical model" refers to a symmetric cosine-only differential blade worth curve and the "new model" represents a 3^{rd}-order polynomial + cosine model for fitting the differential worth data. The new model allows for the asymmetric slightly bottom-peaked distribution that is usually observed for the differential worth curves within the UMLRR.

The measured critical height had Blades 1 – 4 banked at 15.3 inches withdrawn with the regulating blade at 8 inches out. The tabulated excess reactivity is the remaining worth associated with the movable blade length above the critical height (full out is 26 inches withdrawn).

Because of the low total worth, only two data points were taken for the regulating blade. Therefore, the new model could not be used with the limited experimental data available for the regulating blade (need a minimum of 5 data points). Thus, for the total worth and total excess reactivity of all blades, the regulating blade data using the cosine-only fit was used for both cases reported here.

Concerning the curve fits, there is a fair amount of experimental uncertainty in the raw differential worth data, especially for Blades 2 and 4 -- as apparent from visual inspection of the curve fits (see Fig. 7 below, for example) and via the R^2 value noted in the above table. Also, in all cases, the new model gives significantly better fits relative to the theoretical model due mainly to the real asymmetric nature of the measured data. This difference in the two models, forced symmetry for the theoretical model versus potential asymmetry within the new model, also accounts for part of the difference in the prediction of the total excess reactivity for the UMLRR M-1-3 startup core. However, the poor comparison for the excess reactivity values is mostly due to the overall poor curve fits (that are due to the large variation in the measured data). Neither excess reactivity value is overly reliable, but it is expected that the real excess reactivity in the LEU startup core was closer to 4 %Δk/k than the 3 %Δk/k value (as observed from operational experience).

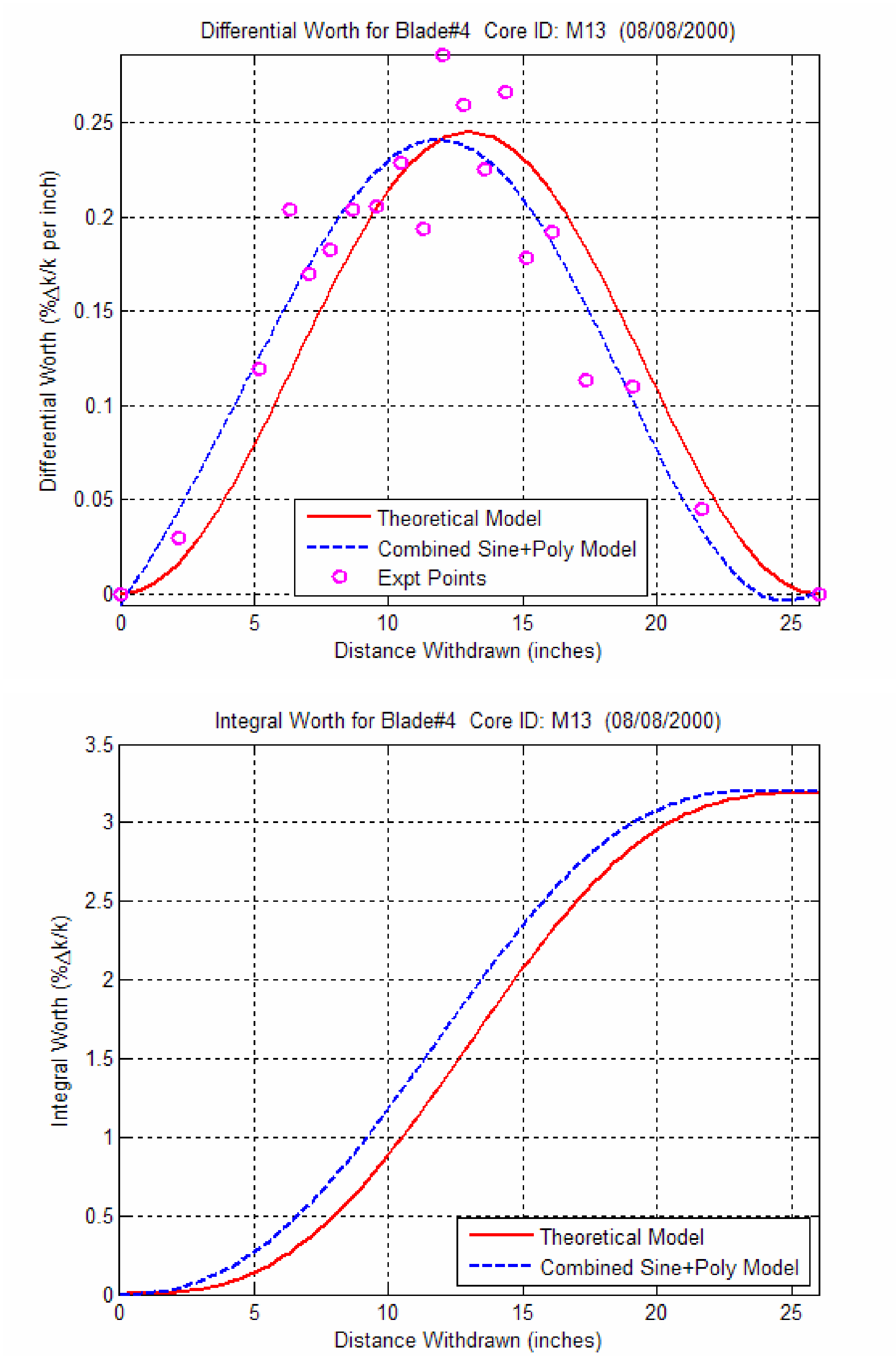


Fig. 7 Typical example of the raw measured data and resultant curve fits for the differential and integral blade worth curves.
(These data show the measured results for Blade 4 in the M-1-3 startup core. Note also that this case has an unusually large number of data points, where 8 – 10 points is more typical.)

Table 2 Computed results for M-1-3 startup core using an updated 3-D VENTURE model with data from the SCALE6 v7n238 library (August 2010).

	Theoretical Model (simple cosine fit)			New Model (3^{rd} order polynomial + cosine fit)		
Blade #	**Total Worth %Δk/k**	**Fit Quality R^2 Value**	**Excess Reactivity %Δk/k**	**Total Worth %Δk/k**	**Fit Quality R^2 Value**	**Excess Reactivity %Δk/k**
Blade 1	2.65	0.94	0.87	2.81	0.99	0.80
Blade 2	2.58	0.95	0.85	2.74	0.99	0.81
Blade 3	3.22	0.94	1.06	3.46	0.99	1.03
Blade 4	3.29	0.94	1.08	3.54	0.99	1.06
Total Worth Blades 1 – 4	11.7	--	3.86	12.6	--	3.70
Regulating Blade	0.45	0.83	0.38	0.49	0.99	0.35
Total Worth All Blades	12.2	--	4.24	13.1	--	4.05

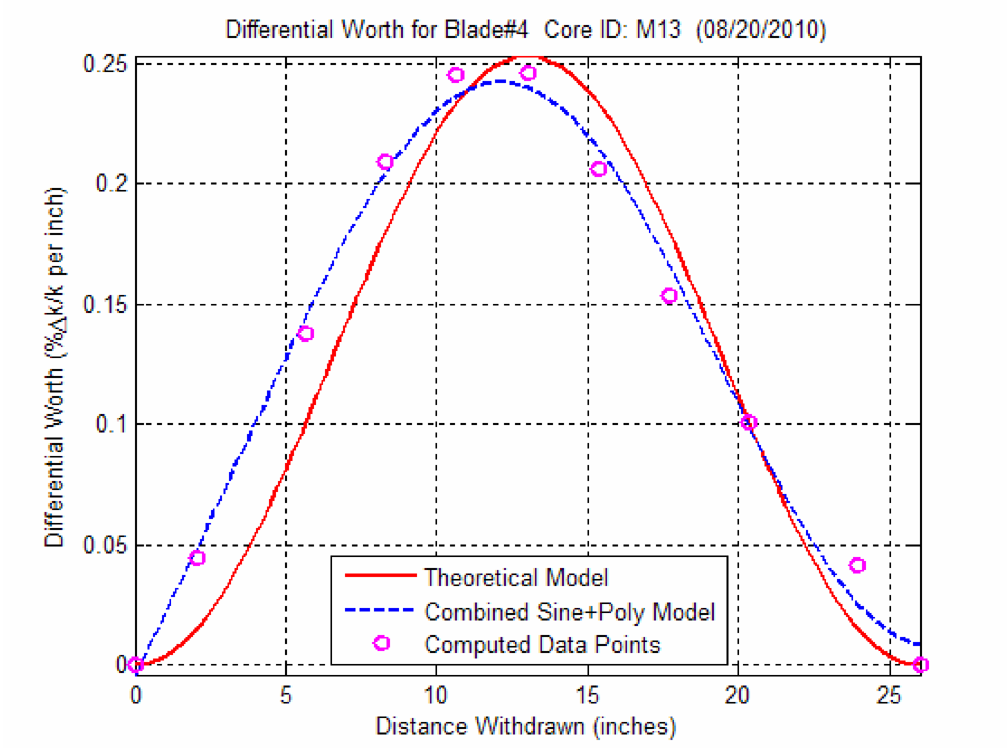
Table 2 Notes:

The base "critical" VENTURE configuration with the four large blades banked at about 15.3 inches withdrawn and the regulating blade fully out gives k = 0.975. Thus, the base model prediction has a bias of roughly -2.5 %Δk/k or more.

The blade worth calculations were done with the goal of keeping the reactor roughly "near critical" (which in this case was roughly k = 0.975 ±0.01). Once the raw k_{eff} data were collected for several blade positions, +0.025 was added to the computed k values from VENTURE to give values closer to unity (to account for the known bias in k_{eff}). These were then used to compute the differential worth estimates and to generate the blade worth curves (i.e. using the adjusted %Δk/k values). The data in the above table were extracted from the resultant integral blade worth profiles.

The data shown here should be compared to the measured results obtained in August 2000 during the startup of the new LEU fueled core (see Table 1). In general, the blade worth predictions from the 3-D VENTURE model agree reasonably well with the real measured data, but they are generally a little on the high side (part of this may be due to the treatment of the -2.5 %Δk/k bias associated with the nearly critical configuration). Other factors are also important, however, such as there is now much less variability in the simulated raw data, which gives better overall curve fits (i.e. compare the R^2 values and Fig. 8 below versus Fig. 7).

Finally, we note that the VENTURE model for the regulating blade has traditionally over-predicted the regulating blade worth because of the homogenization procedure used in the model -- here the computed regulating blade worth is more than 50% higher than the approximate measured result). Thus, the VENTURE regulating blade worth data are known to be suspect, and probably should not be used directly as given in the above table.



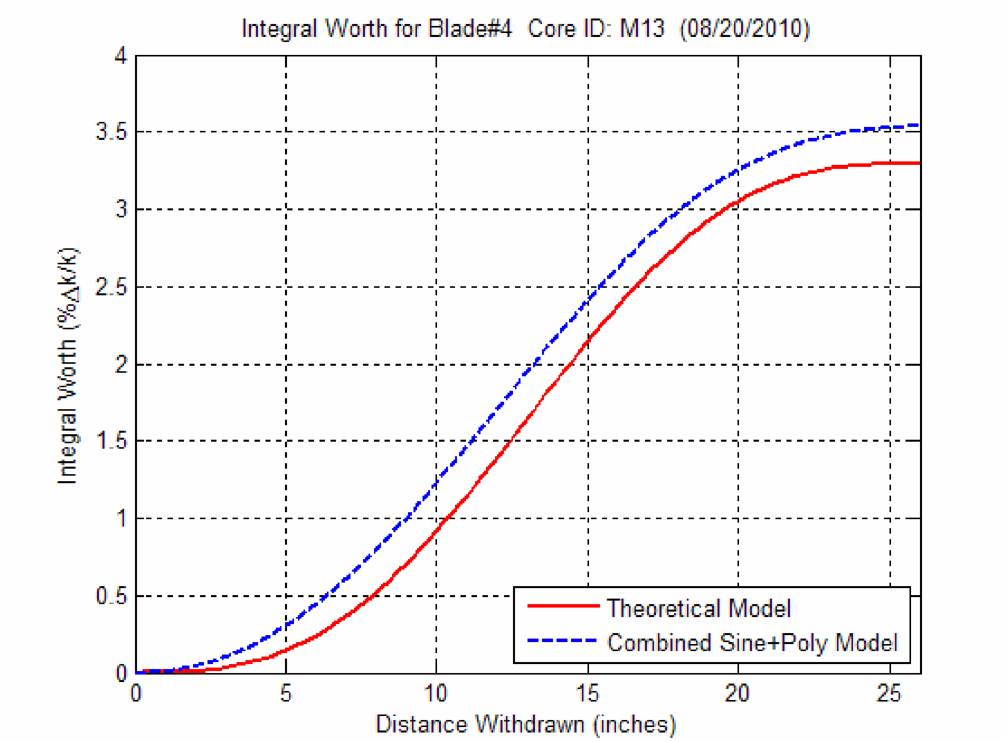


Fig. 8 Typical example of the raw data from the 3-D VENTURE calculations and the resultant curve fits for the differential and integral blade worth curves.

Table 3 Computed results for M-1-3 startup core based on a detailed MCNP model of the UMLRR (January 2011).

	Theoretical Model (simple cosine fit)			New Model (3^{rd} order polynomial + cosine fit)		
Blade #	**Total Worth %Δk/k**	**Fit Quality R^2 Value**	**Excess Reactivity %Δk/k**	**Total Worth %Δk/k**	**Fit Quality R^2 Value**	**Excess Reactivity %Δk/k**
Blade 1	2.65	0.92	0.87	2.83	0.96	0.85
Blade 2	2.64	0.97	0.86	2.71	0.98	0.83
Blade 3	3.39	0.91	1.11	3.55	0.93	1.10
Blade 4	3.47	0.94	1.14	3.64	0.97	1.08
Total Worth Blades 1 – 4	12.2	--	3.98	12.7	--	3.86
Regulating Blade	0.34	0.83	0.29	0.35	0.98	0.26
Total Worth All Blades	12.5	--	4.27	13.1	--	4.12

Table 3 Notes:

We now have a new detailed MCNP model of the M-1-3 core and we are in the process of trying to validate the model to the extent possible with experimental data taken during the startup of the LEU core for the UMLRR (and by comparison to VENTURE calculations). The base "critical" MCNP configuration with the four large blades banked at about 15.3 inches withdrawn and the regulating blade at 8" out has k_{eff} = 0.985. Thus, the base model prediction has a bias of about -1.5 %Δk/k (the VENTURE model has a bias of roughly -2.5 %Δk/k as noted above). In an attempt to find the cause of this bias, we have looked at a number of things where, in particular, one change was to increase the graphite density to 1.8 g/cc (instead of 1.6 g/cc). This brought the MCNP reference “critical” k_{eff} to about 0.990 (a little better, but still low). Although this density is on the high end of the quoted range for reactor grade graphite, we decided to compute the MCNP blade worths for the M-1-3 configuration with this base configuration (i.e. the higher graphite density).

The blade worth calculations here were done with the goal of keeping the reactor near critical and the same blade positions were used as done for the similar set of computations with the 3-D VENTURE model. These locations are somewhat "odd" but they correspond to the same positions available in the discrete VENTURE model (although greater flexibility exists with MCNP to put the blades at any desired location). Once the raw data were collected, 0.01 was added to the computed k_{eff} values from MCNP to bring the values closer to unity (to account for the negative 1% bias). These adjusted values were then used to compute the differential worth estimates used to generate the blade worth curves (i.e. using the adjusted %Δk/k values). This was the same procedure used to generate the blade worth curves for the 3-D VENTURE model in summer 2010.

The MCNP model used 10 million histories (5000 particles per cycle with 2000 cycles) after the fission source had converged to generate the nominal k_{eff} for each different blade configuration.

This number of histories resulted in a standard deviation of about 0.025 %Δk/k for each case. This uncertainty, although small for the estimate of k_{eff}, actually leads to a nontrivial uncertainty in the predicted Δk/k values for each step (the computed Δk/k values ranged roughly between 0.1 and 0.5 % for the four large control blades). Thus, more scatter in the simulated differential blade worth data was expected (relative to the 3-D VENTURE results), and this was indeed observed as apparent in the computed R^2 values in Table 3 and in the example blade worth curves shown in Fig. 9. The MCNP uncertainty, however, was on par or lower than the measurement uncertainty, so the MCNP-computed results were indeed quite acceptable for comparison purposes.

For the low worth regulating blade, however, 50 million histories were needed as well as relatively large Δz increments to keep the statistical uncertainties to reasonable values. For this blade, the Δk/k values were generally in the range of 0.05 to 0.15 % and the 1σ value for each k_{eff} calculation was about 0.011 %Δk/k. However, even with the inherent statistical uncertainty, the curve fit for the "new model" was quite good for this case (recall that there were only two measured points for the regulating blade, so that the enhanced curve fit model could not even be used with the actual experimental data). Finally, within this context, we should note that the quality of fit for the regulating blade worths tend to be quite different for the symmetric theoretical model vs. the asymmetric curve fits, because the four large control blade are inserted to their largest operating depth when computing the regulating blade worths (about 15.3″ withdrawn) -- and this leads to the largest actual asymmetry that is observed in the differential blade worth curves.

Concerning the actual worth values and estimate of the beginning-of-life (BOL) excess reactivity, the MCNP and 3-D VENTURE models were very comparable for the four large control blades, but the MCNP result for the regulating blade is probably the best estimate available, with a total worth of about 0.35 %Δk/k. Here the "measured" result is considered to be very unreliable because only two data points were taken and the cosine-only model was used for the differential worth curve fit (which is known to be in error – especially for the regulating blade). In addition, as noted above, the VENTURE result is known to be over-predicted because of the homogeniza-tion procedures that were required. Thus, at present, the MCNP value for the regulating blade is indeed our best estimate of this quantity. Finally, we note that, for the BOL excess reactivity, most of the available data converge on a result that is near 4 % Δk/k and this is probably quite reasonable based on operational experience.

Thus, within the uncertainty limits associated with the measured data, it appears that both the new MCNP model and the current 3-D VENTURE model give a good overall representation of the UMLRR M-1-3 startup core for a number of global reactivity-related parameters. The only exception here is for the regulating blade worth estimate using VENTURE (which is known to give high estimates), and for the computation of the absolute critical k_{eff} value (which is low for both the MCNP and VENTURE models).

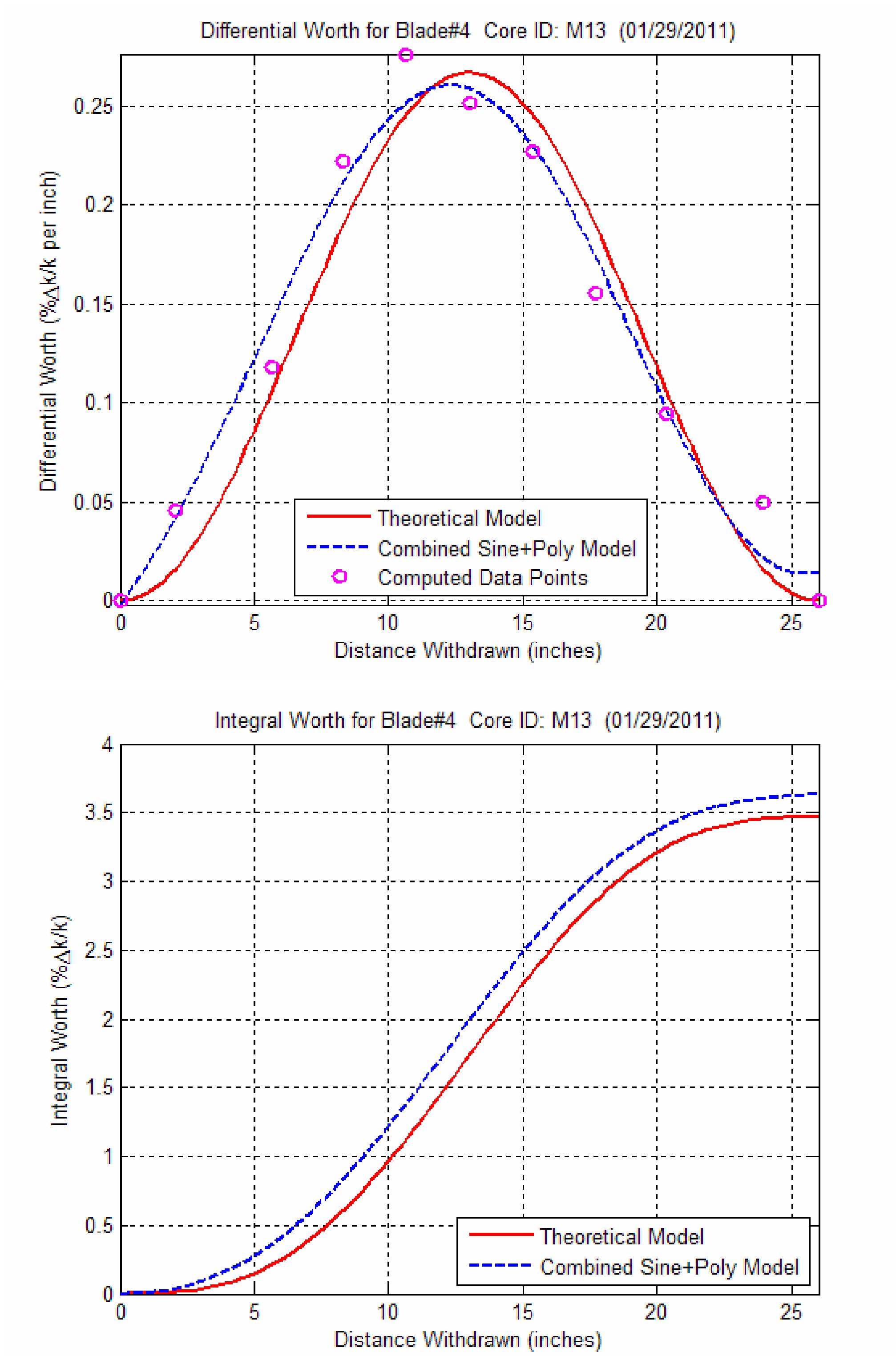


Fig. 9 Typical example of the raw data from the MCNP calculations and the resultant curve fits for the differential and integral blade worth curves.

Future Work

Clearly more testing and comparisons are needed, but the preliminary consensus that can be obtained from Tables 1 – 3 (and their corresponding explanatory comments) is that the MCNP blade worth data and estimated excess reactivity are certainly comparable to the measured data and VENTURE results. In fact, considering that there is so much uncertainty in the actual measured data, one might be able to argue that the MCNP results for some of these quantities may be even more reliable that the measured data (for the regulating blade, for example). However, as noted above, additional reactivity-related results and some thermal flux profiles were also measured in the M-1-3 startup core (see Refs. 2 and 3), and we certainly want to use MCNP to compare to these measurements -- and this is indeed the next immediate step in our current validation effort.

Beyond some further comparisons with the M-1-3 core, the next major step for this work is to make the necessary MCNP model changes to generate the M-2-5 core configuration (with the several in-core modifications and the replacement of three beam ports with a simple model of the fast neutron irradiator), and to account for the 35 – 40 MWD burnup that has been achieved with the current core configuration. These modifications will take some time (especially the treatment of depletion effects within MCNP), and progress on these changes and on other aspects of this project (like the MCNP gamma cave modeling effort) will be forthcoming in the next progress report -- which is expected in the mid to late May 2011 timeframe.

References

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3. J. R. White and L. Bobek, "Startup Test Results and Model Evaluation for the HEU to LEU Conversion of the UMass-Lowell Research," 24th International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR 2002), San Carlos de Bariloche, Argentina (Nov. 2002).