NOTES: **Prepared in June 2015 with latest update by JRWhite in July 2015 (and again in March 2017)**
This file focuses on the flow distribution calculation - all axial power info in separate file
Here we do calcs for both the UMLRR and WPI fuel elements
For the bypasses, all the calcs have 5 RBs, 4 control blades , and 1 RegBlade
We also do a calc based on only flow area for comparison purposes
Basic geometry parameters and assumption are tabulated at the top and then the PLTEMP input is prepared below
This file is based on the original work done by JRWhite back in 1991 for the HEU to LEU conversion.
Added the power-to-flow plot on 7/30/15
Reviewed in March 2017 -- Fixed a couple of typos in the comments and changed the # channels from 19 to 18 in the min flow area calc for the fuel channels...
This was modified to account for the fact that the two end channels are only approximately 1/2 the size of the interior channels (19 full channels was simply not correct).
This change only affected the flow area distribution for the no-friction case (Tables 8 and 9 in the safety analysis report), but this was only used for comparison purposes anyway.
Thus, this change does not affect any of the results and conclusions from the PLTEMP full-core analysis.

Fuel Assembly Info (units ==> centimeters)

		UMLRR	WPI
fuel	top channel area (assume 2.6" x 2.6")	43.613	43.613
	top channel length (about 4.5" for top end box)	11.430	11.430
	plate height	63.500	62.548
	channel width	6.604	6.706
	channel thickness	0.296	0.271
	bottom channel area (assume 2.6" x 2.6")	43.613	43.613
	bottom channel length (about 6" for grid plate)	15.240	15.240
	min flow area	35.222	32.698
rad basket	flow area (1.87" diameter hole)	17.719	
	length (35")	88.900	
	min flow area	17.719	
control blade	shroud area (10.844 x 0.75)	52.471	
	blade area (10.65 x 0.375)	25.766	
	top control in flow area (shroud - blade)	26.705	
	top length (30")	76.200	
	middle control out flow area	52.471	
	middle length (21")	53.340	
	bottom (10.844 x.47) -- very conservative since ignore holes	32.882	
	bottom length (6")	15.240	
	min flow area	26.705	
regblade	shroud area (2.465 x 2.465)	39.201	
	blade area (2.125 x 2.125)	29.133	
	top control in (shroud - blade)	10.068	
	top length (26")	66.040	
	middle control out	39.201	
	middle length (25")	63.500	
	bottom (grid box)	43.613	
	bottom length (6")	15.240	
	min flow area	10.068	
	convert cm to m	100	
	convert cm^2 to m^2	10000	

UMLRR Flow Areas (cm^2)

# fuel assy	fuel	5 rad baskets	4 large blades	1 regblade	total
20	704.435	88.595	106.819	10.068	909.918
21	739.657	88.595	106.819	10.068	945.140
22	774.879	88.595	106.819	10.068	980.362
23	810.101	88.595	106.819	10.068	1015.584
24	845.323	88.595	106.819	10.068	1050.805
25	880.544	88.595	106.819	10.068	1086.027
26	915.766	88.595	106.819	10.068	1121.249

UMLRR Normalized Flow Areas

# fuel assy	fuel	5 rad baskets	4 large blades	1 regblade	total
20	0.774	0.097	0.117	0.011	1.000
21	0.783	0.094	0.113	0.011	1.000
22	0.790	0.090	0.109	0.010	1.000
23	0.798	0.087	0.105	0.010	1.000
24	0.804	0.084	0.102	0.010	1.000
25	0.811	0.082	0.098	0.009	1.000
26	0.817	0.079	0.095	0.009	1.000

WPI Flow Areas (cm^2)

# fuel assy	fuel	5 rad baskets	4 large blades	1 regblade	total
20	653.957	88.595	106.819	10.068	859.440
21	686.655	88.595	106.819	10.068	892.138
22	719.353	88.595	106.819	10.068	924.835
23	752.050	88.595	106.819	10.068	957.533
24	784.748	88.595	106.819	10.068	990.231
25	817.446	88.595	106.819	10.068	1022.929
26	850.144	88.595	106.819	10.068	1055.627

WPI Normalized Flow Areas

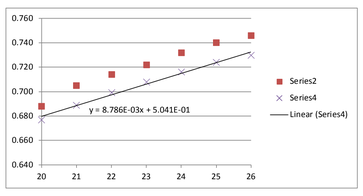
# fuel assy	fuel	5 rad baskets	4 large blades	1 regblade	total
20	0.761	0.103	0.124	0.012	1.000
21	0.770	0.099	0.120	0.011	1.000
22	0.778	0.096	0.116	0.011	1.000
23	0.785	0.093	0.112	0.011	1.000
24	0.792	0.089	0.108	0.010	1.000
25	0.799	0.087	0.104	0.010	1.000
26	0.805	0.084	0.101	0.010	1.000

PLTEMP Data for LEU Core Flow Distribution Calculation

Card 0100			
ANAME	case description	umlrr_flow21	wpi_flow21
Card 0200			
IH	heat transfer correlation option	0	
IB	boiling correlation option	0	
ICHF	CHF correlation option	0	
NFTYP	number of fuel types	1	
NCTYP	number of bypass types	3	
NEDIT	number of Del P intervals between edits	20	
NAXDIS	axial temp calc flag (0/1 no/yes)	0	
NELPRT	element edit flag (ULowell mod - usually zero)	0	
Card 0300	(fuel type 1)		
NELF	number of fuel elements	21	
NF	number of axial regions	3	
WFGES	guess for flow rate (kg/s)	1.00	
FB	HCF for bulk water temp rise	1.00	
FQ	HCF for heat flux	1.00	
FH	HCF for heat transfer coeff	1.00	
Card 0301	(fuel type 1)		
FZ(J)	axial peaking factors (NELF entries) -- no effect here	1.50	
Card 0302	(fuel type 1) (axial region 1) (top)		
AF	flow area (m^2)	4.361E-03	4.361E-03
DF	hydraulic diameter (m)	6.604E-02	6.604E-02
LF	length of region (m)	1.143E-01	1.143E-01
ZF	entrance coeff (reentrant pipe) -- all fric losses based on Mott 5th Ed	1.000E+00	1.000E+00
Card 0302	(fuel type 1) (axial region 2 - must be fuel)		
AF	flow area (m^2) (calc from card 305 if zero)	0.000E+00	0.000E+00
DF	hydraulic diameter (m) (calc internally if 0)	0.000E+00	0.000E+00
LF	length of region (m)	6.350E-01	6.255E-01
ZF	entrance coeff (reentrant pipe)	1.000E+00	1.000E+00
Card 0302	(fuel type 1) (axial region 3)		
AF	flow area (m^2) (calc from card 305 if zero)	4.361E-03	4.361E-03
DF	hydraulic diameter (m) (calc internally if 0)	6.604E-02	6.604E-02
LF	length of region (m)	1.524E-01	1.524E-01
ZF	entrance+exit coeff (2 sudden expansions)	2.000E+00	2.000E+00
Card 0303			
FCOEF	friction factor coeff	0.316	
FEXPF	exponent in friction factor correlation	0.250	
Card 0304			
NCHNF	number of coolant channels	19	
IDF	fuel material option (03/01 UMLRR U3Si2-AL /WPI UAlx-Al)	3	1
IDC	clad type (3 - Al 6061)	3	
UDEN	uranium density (g/cc) (w/o if IDF = 0)	3.420E+00	1.700E+00
UNFUEL	width of unfueled end of fuel plate (m)	2.595E-03	3.103E-03
L	length of fuel region (m)	5.969E-01	5.969E-01
CLAD	clad thickness (m)	3.800E-04	3.810E-04
TAEM	meat thickness (m)	5.100E-04	7.620E-04
Card 0305	(central channels)		
AFF	flow area (m^2)	1.957E-04	1.817E-04
DFF	hydraulic diameter (m) (calc internally if zero)	0.000E+00	0.000E+00
PERF	wetted perimeter (m)	1.380E-01	1.395E-01
XIF	heated perimeter (m) (calc internally if zero)	0.000E+00	0.000E+00
Card 0305	(end channels)		
AFF	flow area (m^2)	9.784E-05	9.083E-05
DFF	hydraulic diameter (m) (calc internally if zero)	0.000E+00	0.000E+00
PERF	wetted perimeter (m)	6.900E-02	6.977E-02
XIF	heated perimeter (m) (calc internally if zero)	0.000E+00	0.000E+00
Card 0306			
CIRCF	width of fuel plate (repeat 18 times)	6.604E-02	6.706E-02
Card 0307	(don't forget dummy endplates - RP = 0 for UMLRR only)		
FACTF	RP factor by plate (NELF*18 entries)	1.00	1.00
	loop over 3 types of bypasses (if present)		
Card 0400	(bypass 1 - radiation baskets)		
NCRS	number of bypasses of this type	5	
NC	number of axial regions	1	
WCGES	guess for flow rate (kg/s)	1.00	
Card 0401			
AC	flow area (m^2)	1.772E-03	
DC	hydraulic diameter (m)	4.750E-02	
LC	length of region (m)	8.890E-01	
ZC	entrance+exit loss coeff (contract+expand)	1.500E+00	
Card 0402			
FCOEC	friction factor coeff	3.160E-01	
FEXPC	exponent in friction factor correlation	2.500E-01	
Card 0400	(bypass 2 - control blades)		
NCRS	number of bypasses of this type	4	
NC	number of axial regions	3	
WCGES	guess for flow rate (kg/s)	1.00	
Card 0401	(top) -- control in --		
AC	flow area (m^2)	2.670E-03	
DC	hydraulic diameter (m)	9.296E-03	
LC	length of region (m)	7.620E-01	
ZC	entrance loss coeff (reentrant pipe)	1.000E+00	
Card 0401	(middle) -- control out --		
AC	flow area (m^2)	5.247E-03	
DC	hydraulic diameter (m)	3.564E-02	
LC	length of region (m)	5.334E-01	
ZC	entrance loss coeff (sudden expansion)	2.411E-01	
Card 0401	(bottom) -- grid region --		
AC	flow area (m^2)	3.288E-03	
DC	hydraulic diameter (m)	2.288E-02	
LC	length of region (m)	1.524E-01	
ZC	loss coeffs (use two sudden expansions)	2.000E+00	
Card 0402			
FCOEC	friction factor coeff	3.160E-01	
FEXPC	exponent in friction factor correlation	2.500E-01	
Card 0400	(bypass 3 - regulating rod)		
NCRS	number of bypasses of this type	1	
NC	number of axial regions	3	
WCGES	guess for flow rate (kg/s)	1.00	
Card 0401	(top) -- control in --		
AC	flow area (m^2)	1.007E-03	
DC	hydraulic diameter (m)	8.636E-03	
LC	length of region (m)	6.604E-01	
ZC	entrance loss coeff (reentrant pipe)	1.000E+00	
Card 0401	(middle) -- control out --		
AC	flow area (m^2)	3.920E-03	
DC	hydraulic diameter (m)	6.261E-02	
LC	length of region (m)	6.350E-01	
ZC	entrance loss coeff (sudden expansion)	5.523E-01	
Card 0401	(bottom) -- grid box --		
AC	flow area (m^2)	4.361E-03	
DC	hydraulic diameter (m)	6.554E-02	
LC	length of region (m)	1.524E-01	
ZC	entrance loss coeff (sudden expansion)	1.000E+00	
Card 0402			
FCOEC	friction factor coeff	3.160E-01	
FEXPC	exponent in friction factor correlation	2.500E-01	
Card 0500			
DPO	initial Del P (MPa)	1.000E-03	
DDP	Del P increment (MPa)	2.500E-04	
DPMAX	max Del P (MPa)	4.000E-03	
POWER	total power (MW) (for portion modelled)	1.000E+00	
TIN	inlet water temp (C)	4.300E+01	
P	inlet pressure (MPa) (about 25 psi converted to Mpa)	1.724E-01	
Card 0600			
ITER	max number of iterations	100	
CONV	convergence ctiterion	0.0001	
ETA	flow instability parameter (default=25)	25.00	
Card 0700			
NN	number of axial interfaces (nodes+1)	rest not needed	
Card 0701		for flow	
ZR	distance of interface from inlet (normalized)	distribution	
QVZ	relative power density at interface	(fz = 1.5 for hot assy)	
Card 0702			
NIJK	number of channels for axial edits		
Card 0703	(repeat NIJK times)		
NII	element type		
NJJ	element number		
NKK	channel number		

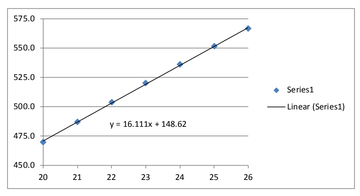
Summary Results

	UMLRR Assembly		**WPI Assembly**	
# fuel assy	flow area calc	PLTEMP calc	flow area calc	PLTEMP calc
20	0.783	0.688	0.771	0.677
21	0.792	0.705	0.779	0.689
22	0.799	0.714	0.787	0.699
23	0.806	0.722	0.794	0.708
24	0.813	0.732	0.801	0.716
25	0.819	0.740	0.808	0.724
26	0.825	0.746	0.814	0.730



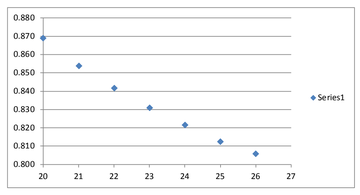
Note: need a conversion factor to go from assembly mass flow rate (kg/s) in PLTEMP to overall pump volumetric flow rate in gal/min (gpm)

# fuel assy	Conv. Factor
20	469.8
21	487.0
22	503.7
23	520.0
24	535.9
25	551.4
26	566.5



Note: the power to flow ratio vs Nassy is also of interest. As the # assy increases, the power per assy decreases (for constant Ptot), but the flow rate per assy aslo decreases. Thus, addressing how the power to flow (kW/gpm) changes is important.

Ptot (kW)	1000	Qpump (gpm)	1700
# fuel assy	kW/assy	gpm/assy	kW/gpm
20	50.0	57.5	0.869
21	47.6	55.8	0.854
22	45.5	54.0	0.842
23	43.5	52.3	0.831
24	41.7	50.7	0.822
25	40.0	49.2	0.812
26	38.5	47.7	0.806



Note: In the documentation for this work I decided to treat this conversion factor a little differently. I wrote it as wassy = 0.0630 (f/N) Qpump (gpm)
where N = Nassy and f = 0.50 + 0.0088N
Let's use these to compute some of the same data as before (just as a check)

Ptot (kW)	1000		Qpump (gpm)	1700		mass flux (kg/s/m^2)	
# fuel assy	kW/assy	f	gpm/assy	kW/gpm	wchan (kg/s)	UMLRR	WPI
20	50.0	0.676	57.5	0.870	0.201	1.028E+03	1.107E+03
21	47.6	0.685	55.4	0.859	0.194	9.916E+02	1.068E+03
22	45.5	0.694	53.6	0.848	0.188	9.587E+02	1.033E+03
23	43.5	0.702	51.9	0.837	0.182	9.286E+02	1.000E+03
24	41.7	0.711	50.4	0.827	0.176	9.011E+02	9.706E+02
25	40.0	0.720	49.0	0.817	0.171	8.757E+02	9.433E+02
26	38.5	0.729	47.7	0.807	0.167	8.523E+02	9.181E+02

Ptot (kW)	1000		Qpump (gpm)	1650		mass flux (kg/s/m^2)	
# fuel assy	kW/assy	f	gpm/assy	kW/gpm	wchan (kg/s)	UMLRR	WPI
20	50.0	0.676	55.8	0.897	0.195	9.975E+02	1.075E+03
21	47.6	0.685	53.8	0.885	0.188	9.624E+02	1.037E+03
22	45.5	0.694	52.0	0.874	0.182	9.305E+02	1.002E+03
23	43.5	0.702	50.4	0.863	0.176	9.013E+02	9.709E+02
24	41.7	0.711	48.9	0.852	0.171	8.746E+02	9.421E+02
25	40.0	0.720	47.5	0.842	0.166	8.500E+02	9.156E+02
26	38.5	0.729	46.3	0.832	0.162	8.273E+02	8.911E+02

Ptot (kW)	1000		Qpump (gpm)	1600		mass flux (kg/s/m^2)	
# fuel assy	kW/assy	f	gpm/assy	kW/gpm	wchan (kg/s)	UMLRR	WPI
20	50.0	0.676	54.1	0.925	0.189	9.673E+02	1.042E+03
21	47.6	0.685	52.2	0.913	0.183	9.332E+02	1.005E+03
22	45.5	0.694	50.4	0.901	0.177	9.023E+02	9.719E+02
23	43.5	0.702	48.9	0.890	0.171	8.740E+02	9.415E+02
24	41.7	0.711	47.4	0.879	0.166	8.481E+02	9.135E+02
25	40.0	0.720	46.1	0.868	0.161	8.242E+02	8.878E+02
26	38.5	0.729	44.8	0.858	0.157	8.022E+02	8.641E+02

Ptot (kW)	1000		Qpump (gpm)	1400		mass flux (kg/s/m^2)	
# fuel assy	kW/assy	f	gpm/assy	kW/gpm	wchan (kg/s)	UMLRR	WPI
20	50.0	0.676	47.3	1.057	0.166	8.464E+02	9.117E+02
21	47.6	0.685	45.7	1.043	0.160	8.166E+02	8.796E+02
22	45.5	0.694	44.1	1.030	0.154	7.895E+02	8.504E+02
23	43.5	0.702	42.8	1.017	0.150	7.647E+02	8.238E+02
24	41.7	0.711	41.5	1.004	0.145	7.421E+02	7.993E+02
25	40.0	0.720	40.3	0.992	0.141	7.212E+02	7.769E+02
26	38.5	0.729	39.2	0.980	0.137	7.019E+02	7.561E+02

Ptot (kW)	1000		Qpump (gpm)	1300		mass flux (kg/s/m^2)	
# fuel assy	kW/assy	f	gpm/assy	kW/gpm	wchan (kg/s)	UMLRR	WPI
20	50.0	0.676	43.9	1.138	0.154	7.859E+02	8.466E+02
21	47.6	0.685	42.4	1.123	0.148	7.583E+02	8.168E+02
22	45.5	0.694	41.0	1.109	0.143	7.331E+02	7.897E+02
23	43.5	0.702	39.7	1.095	0.139	7.101E+02	7.649E+02
24	41.7	0.711	38.5	1.082	0.135	6.891E+02	7.422E+02
25	40.0	0.720	37.4	1.068	0.131	6.697E+02	7.214E+02
26	38.5	0.729	36.4	1.055	0.128	6.518E+02	7.021E+02