Christopher Regan - Thermal Methodology Description for Monday Morning Call

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Subject: Thermal Methodology Description for Monday Morning Call
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Mr. Regan,

Please find attached the document describing the thermal methodology (3-zone-fr.pdf) and the document containing the detailed resistance calculations (D_BWR_FR.pdf) in support of today's and Wednesdays phone conferences. If NRC's corresponding evaluations are available, please consider sending them to us, so we can resolve any concerns as fast as possible. For Wednesday's phone call please use 856-797-0922 to reach our conference phone.

Regards,

Stefan Anton

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TEXT.htm	5300	
3-zone-fr.pdf	121005	
D_BWR_FR.pdf	43696	
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Options
Expiration Date: None
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ReplyRequested:	No
Return Notification:	None
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Security:	Standard

Junk Mail Handling Evaluation Results
Message is eligible for Junk Mail handling
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CALCULATION OF THE CHANNELED GE-10x10 FUEL ASSEMBLY FLOW RESISTANCE BY THE SHEAR STRESS METHOD

1.0 BACKGROUND

The HI-STORM System is evaluated for storage of bounding GE-10x10 BWR fuel in an MPC-68 canister. An illustration of a GE-10x10 fuel placed inside an MPC-68 storage cell is shown in Figure 1. During fuel storage in the MPC fuel basket cells helium enters the storage cells from the bottom plenum and flows upwards in two parallel flow paths labeled (1) and (2). Flow path (1) is the in-channel helium flow entering the fuel assembly from a bottom flow hole in the lower fitting. Flow path (2) is the helium flow in the annulus area between the fuel storage cell walls and the fuel channel. For a better illustration of the two flow regions, a cross-sectional view of one fuel cell is provided in Figure 2.

The GE-10x10 fuel assembly is an array of 92 fuel rods on a 10x10 square pitch. The fuel assembly is equipped with two large water rods, each replacing 4 fuel rods. The water rods are essentially hollow tubes having top and bottom openings to allow water flow during reactor operations. This physical configuration is duly recognized in characterizing bundle resistance to helium flow [Ref. 1]. Nevertheless, as requested by NRC in the recent September 8, 2006 meeting at the White Flint headquarters, an additional layer of conservatism is embedded in the flow resistances calculations by assuming the water rods to be blocked.

It is heuristically obvious that because of a large number of rods comprising the fuel assembly (92 fuel rods and 2 water rods) and a large number of storage cells in a BWR canister (68 cells) an explicit modeling of fuel assemblies in a global thermal model of the HI-STORM system is prohibitively expensive. In the design basis thermal modeling of the HI-STORM system, the following approach is adopted:

(i) The Channel-to-Cell gap is explicitly modeled in each fuel storage cell.

(ii) The in-channel region is replaced by a porous media over the length between bottom and top plenum with an equivalent flow resistance.

The above modeling approach is illustrated in Figure 2.

To characterize the overall resistance of the in-channel flow, a 3-D model of the GE-10x10 fuel assembly is constructed [Ref 1]. To ensure a bounding evaluation of flow resistance the following assumptions are embedded in the model:

(a) Fuel rods assumed to be full length.
(b) Channel length extended to top plenum.
(c) Bounding grid thickness used.
(d) Bottom fitting modeled as sudden opening.
(e) Bottom fitting lateral flow holes blocked.

Using the 3-D fuel assembly model an array of flow solutions are obtained and the overall fuel resistance characterized by a bounding pressure drop curve [Ref. 1].

2.0 REFINED FLOW RESISTANCE MODEL

It is obvious that because of the narrow flow passages in the bare rods and gridded regions of the fuel assembly the flow resistance of the fueled length to axial helium flow is much greater than the flow resistance from the fuel assembly ends (bottom nozzle, top fitting, handle etc.). This fact is duly recognized in the modeling of the axial flow resistance by defining three distinct zones in the porous media length L as follows:

Zone 1: Length below the active fuel region (L1 = 6.97 in)
Zone 2: Length of active fuel region (L2 = 150 in)
Zone 3: Length above the active fuel region (L3 = 14.53 in)

In the refined flow resistance modeling, the flow resistance of each zone is characterized by post-processing the 3-D fuel model solutions as described in Sections 2.1 and 2.2. For this purpose two approaches to flow resistance characterization are adopted. The first approach is the pressure drop method. This method is suitable when a flow zone is characterized by irregular geometries and the objective is to obtain a lumped resistance to duplicate the pressure drop in that section. The second method is the shear stress method, which is suitable for flow zones characterized by regular geometries. For the 3-zone flow resistance modeling, the pressure drop method is adopted for modeling the inactive regions (Zone 1 and Zone 3) because of the irregular geometry. The shear stress method is adopted for modeling flow resistance in the active fuel region (Zone 2) as this region is characterized by an ordered array of smooth shaped entities (rods and grids).

2.1 Pressure Drop Method for Zones 1 and 3

In the FLUENT CFD program, pressure drop in a porous fluid zone (ΔP) is modeled as follows:

$$\Delta P = D\mu V L_z \qquad \text{(Eq. 1)}$$

where,

D = Flow resistance coefficient ($1/m^2$)
μ = Fluid viscosity (kg/m-s)
V = Superficial fluid velocity (m/s)
L_z = Zone length (m)

To represent the GE-10x10 channeled cross-section's upper and lower non-active zones as equivalent porous mediums, the flow resistance coefficient D is computed using the pressure losses computed by the 3-D CFD model in Zone 1 and Zone 3 as follows:

Step 1: Obtain the helium volumetric flow, Q for an impressed fuel assembly pressure differential.
Step 2: Compute helium superficial velocity, V (= Q/A where A is the channel cross-sectional area).
Step 3: Obtain the Zone 1 and Zone 2 pressure drops (ΔP) from the CFD solution.
Step 3: Compute D using Eq. 1, V and ΔP from Steps 2 and 3 above.

2.2 Shear Stress Method for Zone 2

As stated in Section 2, the shear stress method is suitable for flow zones characterized by regular geometries, such as an array of rods. This method is used to characterize the flow resistance of the active fuel region (Zone 2). To account for geometric discontinuities the active fuel region is sliced in a suitable number of constant-geometry sub-regions. Based on the GE-10x10 fuel bundle layout, a total of 17 slices are identified in the active fuel region (8 grid spacers, 7 bare rod sections (between grid spacers), 1 bare rod section below the 1st grid spacer and 1 bare rod section above the 8th grid spacer). In each sub-region, an area averaged shear stress τ_{av} over all wetted surfaces (fuel rods, channel, water rod OD[1] and grids) is post-processed from the 3-D CFD model solution. Using τ_{av} and the procedure for obtaining flow resistance coefficients from wall stresses [Ref. 1], flow resistance coefficients D_k for all slices ($k = 1,2,\ldots,17$) are computed. The flow resistance coefficient for Zone 2 is obtained by computing the length-weighted average of the sub-region resistances (D_k) and slice lengths (L_k).

3.0 FLOW RESISTANCE RESULTS

To embed an additional layer of conservatism in the in-channel flow resistances, two additional assumptions (See Section 1 for other conservatisms) are applied to the flow resistance calculations presented herein. These are:

- (i) Water rod flow is blocked.
- (ii) The highest flow resistance CFD solution, Run #10[2] used for post-processing.

The 3-Zone in-channel flow resistances are post-processed in the manner described in Sections 2.1 and 2.2. The flow resistance results are provided in Table 1.

4.0 REFERENCES

[1] "Pressure loss characteristics for in-cell flow of helium in PWR and BWR MPC storage cells", Report HI-2043285, Rev. 4.

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[1] The flow resistances are computed assuming blocked water rods. For this condition, the water rod OD is the only water rod surface that resists fluid flow.

[2] This case is solved after choking the water rods flow in the CFD model.

Table 1: Flow Resistance Results

Axial Flow Zone	Flow Resistance Coefficient, D ($1/m^2$)	Length of Zone (inch)
Zone 1	0.7628×10^6	6.97
Zone 2	1.001×10^6	150
Zone 3	0.6284×10^6	14.53
Length Weighted Average of Zones 1, 2, and 3	0.9593×10^6	171.5

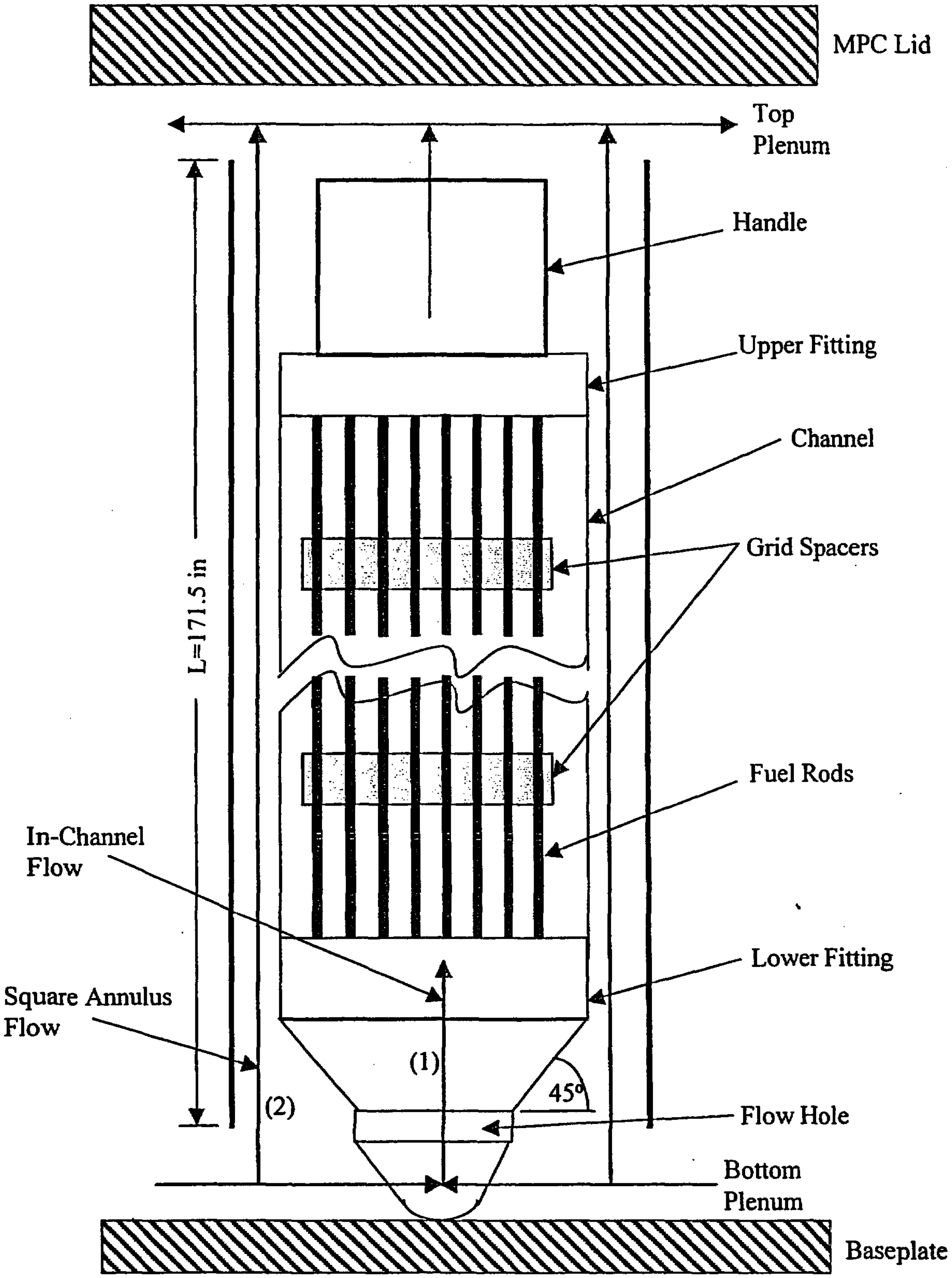

Figure 1 : OUTLINE OF A CHANNELED GE10x10 FUEL ASSEMBLY IN AN MPC-68 STORAGE CELL

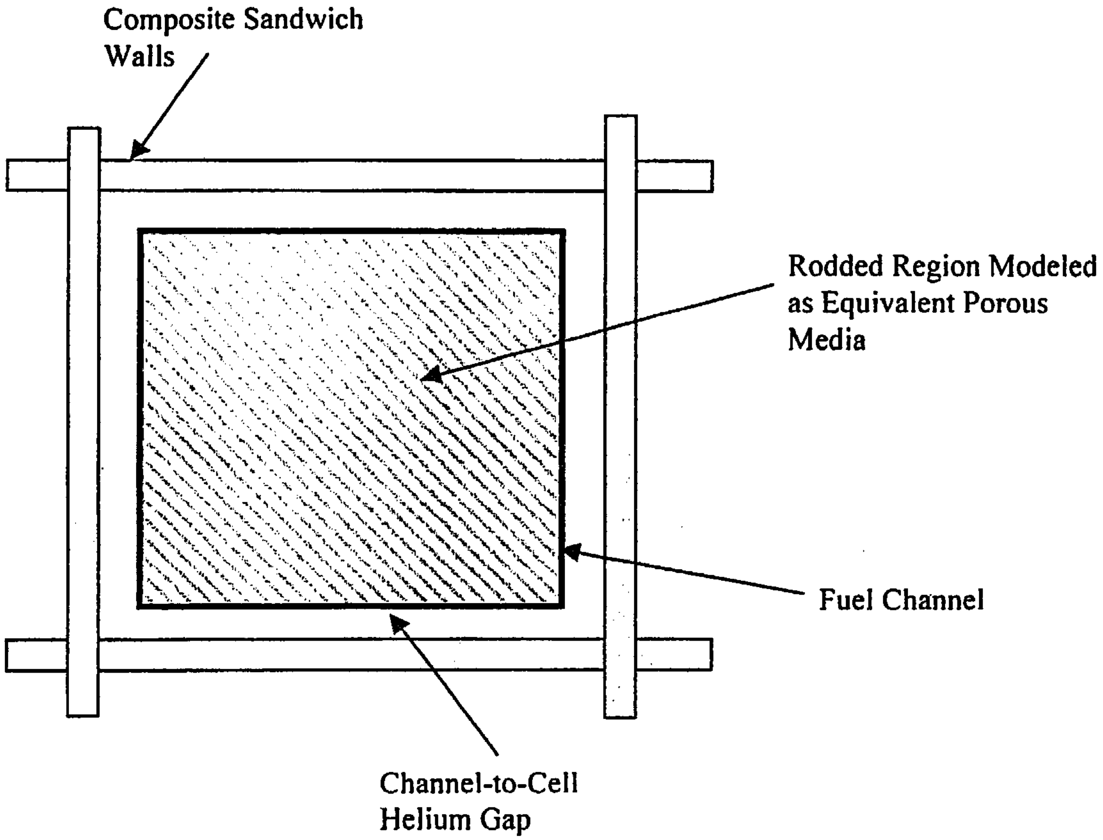

Figure 2 : CLOSEUP VIEW OF THE MPC-68 CHANNELED FUEL CELL SPACES

BWR ACTIVE FUEL (GE-12/14) HYDRAULIC RESISTANCE AREA AVERAGED SHEAR STRESS METHOD

Introduction

Blocked Water Rods in-channel flow resistance of a GE-12/14 Active Fuel Region is computed using the shear stress method described in Appendix C of Ref. 1.

References

[1] Holtec flow resistance report HI-2043285, Rev. 4.
[2] Blocked Water Rods GE-12/14 CFD Run 10.

CFD Solution Postprocessing Results [2]

$$\tau BR := \begin{pmatrix} 2.486\cdot 10^{-3} \\ 2.521\cdot 10^{-3} \\ 2.521\cdot 10^{-3} \\ 2.521\cdot 10^{-3} \\ 2.521\cdot 10^{-3} \\ 2.542\cdot 10^{-3} \\ 2.542\cdot 10^{-3} \\ 2.542\cdot 10^{-3} \\ 2.480\cdot 10^{-3} \end{pmatrix}\cdot Pa$$

Bare Rod Sections Area Averaged Shear Stress

$$\delta z := \begin{pmatrix} 0.404 \\ 0.447 \\ 0.447 \\ 0.447 \\ 0.447 \\ 0.352 \\ 0.352 \\ 0.352 \\ 0.3996 \end{pmatrix}\cdot m$$

Bare Rod Sections Length

$$\tau GR := \begin{pmatrix} 5.174\cdot 10^{-3} \\ 5.174\cdot 10^{-3} \\ 5.174\cdot 10^{-3} \\ 5.174\cdot 10^{-3} \\ 5.176\cdot 10^{-3} \\ 5.178\cdot 10^{-3} \\ 5.178\cdot 10^{-3} \\ 5.177\cdot 10^{-3} \end{pmatrix}\cdot Pa$$

Grid Spacer Sections Area Averaged Shear Stress

$Mic := 5.0264\cdot 10^{-4}\cdot\frac{kg}{s}$ Helium Inlet Mass Flow

$\Delta P1 := 0.16\cdot Pa$ Bottom Inactive Zone Pressure Loss (max)

$\Delta P3 := 0.28\cdot Pa$ Top Inactive Zone Pressure Loss (max)

Helium Properties @ 7 atm, 450F [1]

$\rho := 0.675\cdot\frac{kg}{m^3}$ Density

$\mu := 2.86\cdot 10^{-5}\cdot\frac{kg}{m\cdot s}$ Viscosity

Bundle Dimensions [1]

$dR := 0.010262\cdot m$ Fuel Rods Diameter

$p := 0.012954\cdot m$ Fuel Rods Pitch

$t := 5.08\cdot 10^{-4}\cdot m$ Grids Thickness

$h := 0.02032\cdot m$ Grids Height

$NA := 10$ Bundle Array Size

$Ngn := 8$ Number of Grids

$NR := 92$ Number of Fuel Rods

$NW := 2$	Number of Water Rods
$C := 0.13406 \cdot m$	Channel Opening
$Lafl := 3.81 \cdot m$	Active Fuel Length
$dWi := 0.023368 \cdot m$	Water Rods ID
$dWo := 0.024892 \cdot m$	Water Rods OD

Bare Rods Resistance Parameter

First, calculate the total rods region area (in-channel area minus area occupied by water rods) and the rods region flow area (total rods region area minus rods area).

$Arr := C^2 - NW \cdot \frac{\pi}{4} \cdot dWo^2$	$Arr = 0.017\,m^2$	Rods Region Area
$Afr := Arr - NR \cdot \frac{\pi}{4} \cdot dR^2$	$Afr = 9.39 \times 10^{-3}\,m^2$	Rods Region Flow Area

Next, calculate the rods region porosity (rods region flow area divided by channel gross internal area) and the hydraulic diameter for the rods region flow area (4 x rods region flow area divided by rods region wetted perimeter).

$\varepsilon rr := \frac{Afr}{C^2}$	$\varepsilon rr = 0.522$	Rods Region Porosity
$dhBR := 4 \cdot \frac{Afr}{4 \cdot C + \pi \cdot NR \cdot dR + \pi \cdot NW \cdot dWo}$	$dhBR = 0.01027\,m$	Bare Rods Hydraulic Diameter

Next, calculate the average water rod helium velocity (for fully-developed in-tube laminar flow, the average velocity is one-half the centerline velocity), the rods region volumetric flow rate, and the rods region average actual (not superficial) helium flow velocity.

$Qr := \frac{Mic}{\rho}$	$Qr = 7.447 \times 10^{-4}\,\frac{m^3}{s}$	Rods Region Volumetric Helium Flow
$Vr := \frac{Qr}{Afr}$	$Vr = 0.079\,\frac{m}{s}$	Rods Region Average Actual Helium Velocity

Finally, calculate the flow Reynolds number, friction factor and viscous resistance factor. Reynolds number and friction factor are based on the actual average helium velocity. The viscous resistance factor is mapped onto the superficial area by including the porosity in the denominator.

$Re := dhBR \cdot Vr \cdot \frac{\rho}{\mu}$ $Re = 19.215$ Reynolds Number

$$f := 4 \cdot \frac{\tau BR}{\frac{1}{2} \cdot \rho \cdot Vr^2}$$

Bare Rods Friction Factor

$$f = \begin{pmatrix} 4.685 \\ 4.751 \\ 4.751 \\ 4.751 \\ 4.751 \\ 4.79 \\ 4.79 \\ 4.79 \\ 4.673 \end{pmatrix}$$

$FBR := f \cdot Re$

Laminar Friction Constant

$$FBR = \begin{pmatrix} 90 \\ 91.3 \\ 91.3 \\ 91.3 \\ 91.3 \\ 92 \\ 92 \\ 92 \\ 89.8 \end{pmatrix}$$

$$DBR := \frac{FBR}{2\cdot \varepsilon rr \cdot dhBR^2}$$ Rods Region Viscous Resistance

$$DBR = \begin{pmatrix} 8.174 \times 10^5 \\ 8.289 \times 10^5 \\ 8.289 \times 10^5 \\ 8.289 \times 10^5 \\ 8.289 \times 10^5 \\ 8.359 \times 10^5 \\ 8.359 \times 10^5 \\ 8.359 \times 10^5 \\ 8.155 \times 10^5 \end{pmatrix} \frac{1}{m^2}$$

Gridded Rods Resistance

First, calculate the grids region flow area (rods region flow area minus area occupied by grids) and the grids rods region wetter perimeter (fuel rods wetted perimeter plus water rods wetted perimeter plus grids wetted perimeter plus channel wetted perimeter).

$$Npw := \sqrt{\frac{NA^2 - NR}{NW}}$$ $Npw = 2$ Rod Pitches per Water Rod Space

$$Agr := 4\cdot NR\cdot\left(p - \frac{t}{2}\right)\cdot\frac{t}{2} + 4\cdot NW\cdot\left(Npw\cdot p - \frac{t}{2}\right)\cdot\frac{t}{2} + 4\cdot NA\cdot p\cdot\frac{t}{2}$$ $Agr = 1.37 \times 10^{-3}\,m^2$ Area Occupied by Grids

$Afg := Afr - Agr$ $Afg = 8.019 \times 10^{-3}\,m^2$ Grids Region Flow Area

$$Pwg := 4\cdot C + \pi\cdot NR\cdot dR + \pi\cdot NW\cdot dWo + 4\cdot NR\cdot(p - t) + 4\cdot NW\cdot(Npw\cdot p - t) + 4\cdot NA\cdot p$$ Wetted Perimeter

$Pwg = 8.96\,m$

Next, calculate the grids region porosity (grids region flow area divided by channel gross internal area) and the hydraulic diameter for the grids region flow area (4 x grids region flow area divided by grids region wetted perimeter).

$\varepsilon gr := \frac{Afg}{C^2}$ $\varepsilon gr = 0.446$ Grids Region Porosity

$dhGR := 4 \cdot \frac{Afg}{Pwg}$ $dhGR = 3.58 \times 10^{-3}\,m$ Grids Region Hydraulic Diameter

Next, calculate the grids region average actual (not superficial) helium flow velocity.

$Vg := \frac{Qr}{Afg}$ $Vg = 0.093\,\frac{m}{s}$ Average Grids Region Actual Helium Velocity

Finally, calculate the flow Reynolds number, friction factor and viscous resistance factor. Reynolds number and friction factor are based on the actual average helium velocity. The viscous resistance factor is mapped onto the superficial area by including the porosity in the denominator.

$Re := dhGR \cdot Vg \cdot \frac{\rho}{\mu}$ Reynolds Number

$Re = 7.846$

$$f := 4 \cdot \frac{\tau GR}{\frac{1}{2} \cdot \rho \cdot Vg^2}$$

$$f = \begin{pmatrix} 7.111 \\ 7.111 \\ 7.111 \\ 7.111 \\ 7.114 \\ 7.116 \\ 7.116 \\ 7.115 \end{pmatrix}$$

Gridded Rods Friction Factor

$FGR := f \cdot Re$

$$FGR = \begin{pmatrix} 55.8 \\ 55.8 \\ 55.8 \\ 55.8 \\ 55.8 \\ 55.8 \\ 55.8 \\ 55.8 \end{pmatrix}$$

Laminar Friction Constant

$$DGR := \frac{FGR}{2 \cdot \varepsilon gr \cdot dhGR^2}$$ Grids Region Viscous Resistance

$$DGR = \begin{pmatrix} 4.879 \times 10^6 \\ 4.879 \times 10^6 \\ 4.879 \times 10^6 \\ 4.879 \times 10^6 \\ 4.881 \times 10^6 \\ 4.883 \times 10^6 \\ 4.883 \times 10^6 \\ 4.882 \times 10^6 \end{pmatrix} \frac{1}{m^2}$$

Active Fuel Region Length Weighted Resistance Coefficient (Zone 2)

$$Df := \frac{\left[h \cdot \sum_{k=0}^{7} DGR_k + \sum_{k=0}^{8} \left(DBR_k \cdot \delta z_k \right) \right]}{Lafl}$$

$$Df = 1.001 \times 10^6 \frac{1}{m^2}$$

Inactive Regions Flow Resistance Coefficient

$C := 0.13406 \cdot m$ Channel Opening [1]

$Ac := C^2$ Channel Opening Area

$$Ac = 0.018\,m^2$$

$Vs := \frac{Mic}{\rho \cdot Ac}$ In Channel Superficial Velocity

$$Vs = 0.041\,\frac{m}{s}$$

$L1 := 0.177 \cdot m$ Inactive Bottom Region (Zone 1) Length [2]

$L3 := 0.376 \cdot m$ Inactive Top Region (Zone 3) Length [2]

Bottom Inactive Region (Zone 1) Flow Resistance Coefficient

$D1 := \frac{\Delta P1}{\mu \cdot Vs \cdot L1}$

$$D1 = 7.628 \times 10^5\,\frac{1}{m^2}$$

Top Inactive Region (Zone 3) Flow Resistance Coefficient

$D3 := \frac{\Delta P3}{\mu \cdot Vs \cdot L3}$

$$D3 = 6.284 \times 10^5\,\frac{1}{m^2}$$

Length Weighted Average of Zones 1,2 and 3

$Dav := \frac{(L1 \cdot D1 + Lafl \cdot Df + L3 \cdot D3)}{L1 + Lafl + L3}$

$$Dav = 9.593 \times 10^5\,\frac{1}{m^2}$$