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PRESSURE LOSS CHARACTERISTICS FOR IN-CELL FLOW OF HELIUM IN PWR AND BWR MPC STORAGE CELLS

FOR

GENERIC

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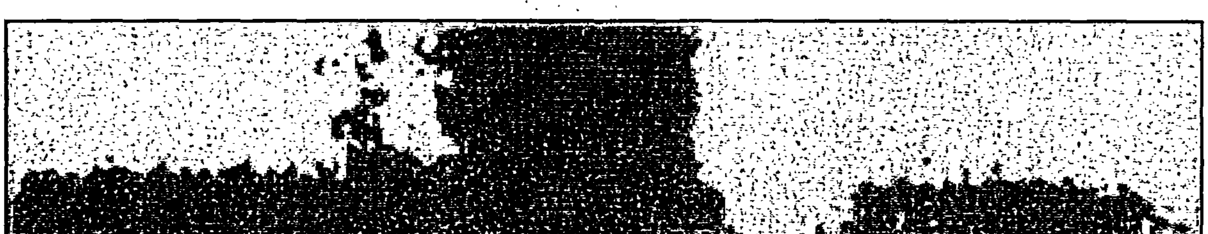

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DOCUMENT CATEGORIZATION

In accordance with the Holtec Quality Assurance Manual and associated Holtec Quality Procedures (HQPs), this document is categorized as a:

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- ☐ Design Criterion Document (Per HQP 3.4)
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- ☐ Other (Specify):

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SUMMARY OF REVISIONS LOG Original Issue (Number of Pages List)	
Title Page	1
Document Issuance and Revision Status	2
Summary of Revisions Log	1
Table of Contents	2
Text	28
Figures	15
Appendix A	5
Attachment 1	8

PROPRIETARY INFORMATION REMOVED

TABLE OF CONTENTS

List of Figures

PROPRIETARY INFORMATION REMOVED

List of Appendices

List of Attachments

CHAPTER 1.0: INTRODUCTION

Density difference driven flow of helium along the length of the stored fuel in the storage cells of Holtec MPCs is an important contributor to the rejection of heat generated by the spent fuel. The thermosiphon action in a Holtec MPC is pictorially illustrated in Figure 1.1.

As would be expected, the rate of helium circulation is strongly influenced by the in-cell resistance to the flow of helium. The object of this technical report is to quantify the parameters needed to characterize the resistance of helium flow in the porous media model in FLUENT [1.1] for thermal analysis of the HI-STORM and HI-STAR systems. To define the porous media parameters, detailed three-dimensional CFD models of the Commercial Spent Fuel (CSF) assemblies are prepared on FLUENT. Separate analyses are performed on a limiting BWR CSF and a PWR CSF.

The flow loss characteristics of CSF manufactured and used in commercial reactors are principally a function of the rod array size. The larger array fuels have the most number of fuel rods arrayed on a smaller pitch. Thus it is heuristically obvious that the largest array fuel within each class (BWR and PWR) are hydraulically limiting. Accordingly, within each limiting array class one commonly used CSF is evaluated in this report. The reference fuel types are: indicated in bold below:

(a) BWR Fuel
Limiting array: 10x10
Fuel Type: **GE-12/14**

(b) PWR Fuel
Limiting array: 17x17
Fuel Type: **Westinghouse 17x17 (OFA)**

In the case of the BWR fuel, the presence of the fuel "channel" (which is actually a square tube) creates two zones of axial flow in the storage cell. In addition to the in-channel (thru-fuel) axial flow, there is a parallel flow path in the "square annulus" between the channel and the storage cells. The two flows will combine in the storage cell space above the channel. The CFD model for the BWR fuel is constructed with an appropriate recognition of the presence of the fuel channel. In the PWR case, the flow scenario is less involved. This is because PWR fuel is a channel-free design having a single helium flow path in its in-cell storage configuration

In Chapter 2, the flow loss parameters for thru-channel flow and storage-cell flow for BWR fuel are obtained as a function of flow velocity based on channel opening and cell opening areas. The thru-channel flow parameters are suitable for use in detailed 3-D MPC models wherein the channeled fuel region (rodded area) and the square annulus flow regions are explicitly modeled. The in-cell flow parameters are intended for use in axisymmetric MPC models[1].

In Chapter 3, the corresponding storage cell pressure loss parameters for PWR fuel are obtained as a function of flow velocity. Because PWR fuel does not feature a flow channel, a single set of pressure drop versus flow data is used to determine pressure loss parameters suitable for detailed 3-D or axisymmetric MPC models.

1.1 About This Document

This work product has been labeled a *safety-significant* document in Holtec's QA System. In order to gain acceptance as a *safety significant* document in the company's quality assurance system, this document undergoes a prescribed review and acceptance process that requires the preparer and reviewer(s) of the document to answer a comprehensive list of questions crafted to ensure that the document has been purged of all errors of any material significance. A record of the review and verification activities is maintained in electronic form within the company's network to enable future retrieval and recapitulation of the programmatic validation process leading to the acceptance and release of this document under the company's QA system. Among the numerous requirements that a document of this genre must fulfill to muster approval within the company's QA program are:

[1] For axisymmetric models the in-cell porous media parameters require mapping from cell opening to cell pitch based area. The mapping is defined in Section 2.4.

- The preparer(s) and reviewer(s) are technically qualified to perform their activities per the applicable Holtec Quality Procedure (HQP).

- The input information utilized in the work effort must be drawn from referencable sources. Any assumed input data is so identified.

- All significant assumptions, as applicable, are stated.

- The analysis methodology, if utilized, is consistent with the physics of the problem.

- Any computer code and its specific versions that may be used in this work has been formally admitted for use within the company's QA system.

- The format and content of the document is in accordance with the applicable Holtec quality procedure.

- The material content of this document is understandable to a reader with the requisite academic training and experience in the underlying technical disciplines.

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In accordance with the foregoing, this report has been prepared pursuant to the provisions of Holtec Quality Procedures HQP 3.0 and 3.2, which require that all safety significant analyses be fully documented such that the analyses can be reproduced at *any time in the future* by a specialist trained in the discipline(s) involved. Because of its function as a repository of all analyses performed on the subject of its scope, this document will require a revision only if an error is discovered in the computations or the equipment design is modified. Additional analyses in the future may be added as numbered supplements to this Package. Each time a supplement is added or the existing material is revised, the revision status of this Package is advanced to the next number and the Table of Contents is amended. Analysis reports are Holtec proprietary documents. They are shared with a client only under strict controls on their use and dissemination. This report is saved as a Permanent Record under the company's QA System.

CHAPTER 2.0: BWR FUEL RESISTANCE

In this chapter, the upflow resistance of a limiting BWR fuel assembly (GE-12/14 10x10) located in an MPC-68 storage cell is obtained. For this purpose, a 3-D CFD model of a GE-12/14 10x10 fuel assembly is constructed and a pressure drop curve $\Delta P_o(V)$ as a function of helium superficial velocity V is obtained. The pressure drop curve is obtained for reference conditions defined below:

Fluid:	Helium
Temperature (T_R):	450°F
Pressure (P_R):	7 atm

Next, the pressure drop curve is fitted to a porous media model of the flow region consistent with the representation in FLUENT [1.1]:

$$\frac{\Delta P_{pm}}{L} = D\mu V + C\rho\frac{V^2}{2}$$

where:

ΔP_{pm} is porous media pressure drop

V is superficial fluid velocity

L is length of porous media

μ, ρ are fluid properties (viscosity and density respectively)

D, C are flow resistance parameters (viscous resistance and inertial resistance coefficients respectively)

D and C are manually adjusted to ensure the following:

(i) The porous media pressure drop bounds the reference pressure drop curve in the lower velocity range.

(ii) ΔP_{pm} departs from ΔP_o with an increasing margin in the higher velocity range.

The second requirement ensures that the pressure drop model remains conservative for helium velocities outside the range of the pressure drop curve.

2.1 CFD Modeling Data

In Figure 2.1 an elevation view of a channeled GE-12/14 fuel assembly in an MPC-68 storage cell is illustrated. Under fuel storage conditions (decay heat generation in the fuel assembly and pressurized helium filling the open spaces in the MPC) helium enters the storage cell from bottom openings (Bottom Plenum) and flows upwards through two parallel paths, labeled (1) and (2). Flow path (1) is the in-channel helium flow entering the fuel assembly from a flow hole in the lower fitting and flow path (2) is the square annulus flow. The two flows merge in an essentially open space above the upper fitting and exit the storage cell from top openings (Top Plenum).

To characterize the storage cell upward flow resistance the storage cell length "L" between top and bottom openings (See Figure 2.1) is modeled on the 3-D FLUENT computer program. It is obvious that for parallel flows the net mass flow in the storage cell (M_{cell}) is a sum of the in-channel flow (M_1) and annulus flow (M_2). The flows are characterized by constructing two 3-D CFD models, namely, a model of the rodded area within the channel (flow path (1)) and a model of the channel-to-cell area (flow path (2)). The pertinent fuel assembly data assembled from proprietary sources in Holtec' possession (see Attachment 1) is provided below:

[Shaded text contains Confidential & Proprietary Information. Do not release to third parties without proprietary safeguards]

Rods Layout:	10x10
Fuel Rods OD:	0.404"
Rods Pitch:	0.51"
Fuel Rods Length:	162"
Number of Fuel Rods:	92
Number of Water Rods:	2

[redacted]

[redacted]

Channel Outside Width: 5.478"

Channel Thickness: 0.1"

The MPC-68 storage cell dimensional data [2.3] is summarized below:

Cell Opening: 6.053"

Cell Pitch: 6.49"

Cell Height: 171.5"

(between top & bottom plenums)

The helium properties at reference conditions (P_R and T_R defined earlier in this chapter) are summarized below:

Viscosity (μ): 2.86×10^{-5} Kg/m-s [2.1]

Density (ρ): $P_R M/[R(T_R+460)]$

where: M is molecular weight of helium (4)

R is Ideal-Gas Constant (0.7302 atm-ft^3/lbmol-°R [2.2])

Using the equation above, ρ computes as 0.0421 lb/ft^3 (0.675 Kg/m^3)

2.2 In-Channel Model

In Figure 2.2, a planar layout of the GE-12/14 fuel assembly is shown. The assembly layout includes two large water rods in the central portion of a regularly spaced fuel rods array. The layout is diagonally symmetric (Symmetry lines aa' and bb' shown in Figure 2.2). The water rods have an open interior space and an array of flow holes near the bottom and top to facilitate fluid flow. The bottom and top ends of the water rods are capped. In Figure 2.3 a dimensioned sketch of the water rods is shown.

Using the assembly layout of Figure 2.2 and fuel assembly data from Section 2.1 a quarter symmetric model of the GE-12/14 fuel assembly is constructed. The fuel assembly model includes the water rods as an empty pipe with top and bottom portions modeled as porous media to include the flow resistance of the flow holes and the bottom flow constrictions (reduced diameter pipe and orifice). For this purpose the water rod is modeled in three sections as illustrated in Figure 2.3. Detailed 3-D FLUENT models of the bottom (Section I) and top (Section II) are constructed to characterize their flow resistances. The mid-section is explicitly included in the quarter symmetric fuel assembly model. Isometric views of the water rod models (Section I and Section II) are shown in Figures 2.4 and 2.5. A planar section of the fuel assembly model is shown in Figure 2.6. For conservatism, the fuel assembly models include the following assumptions:

a) The channel is assumed to extend to the top of the fuel handle.
b) The bottom fitting flow transition is modeled as a sudden expansion.

The water rod models are employed in constructing a pressure drop curve as a function of in-rod velocity for the top and bottom sections. Next the curves are fitted to a porous media pressure drop model. The porous media models define the input parameters α and C for Sections I and II of the water rods in the in-channel fuel assembly model. The in-channel model is employed in constructing the pressure drop curve for flow path (1) depicted in Figure 2.1. The computer runs and post-processing of results are provided in Section 2.4.

2.3 Annulus Model

The annulus region is essentially a tall flow gap between the channel and storage cell walls. For conservatism, the annulus length is overstated by assuming the channel to extend to the top of the fuel handle (See assumption a) in the previous Section). The annulus flow model is illustrated in Figure 2.7. The model is employed in the pressure drop curve for flow path (2) depicted in Figure 2.1. The computer runs and post-processing of results are provided in the next section.

2.4 Flow Resistance Computations

As discussed in this chapter, 3-D FLUENT models are constructed to characterize the flow resistance of an MPC-68 storage cell occupied by a limiting BWR fuel assembly (GE-12/14). The models address the resistance of two parallel flow paths through the storage cell, namely, in-channel flow and square annulus flow (See Figure 2.1). To model the in-channel flow a quarter symmetric model of a GE-12/14 fuel assembly is constructed as shown in Figure 2.6. The model includes the hollow water rods.

The water rods are provided with an array of flow holes at the bottom and top (Figure 2.3). The flow holes resistance is addressed in two 3-D sub-models of the water rod bottom and top sections shown in Figures 2.4 and 2.5. These two sub-models are employed in constructing pressure drop curves for the top and bottom sections of the water rod. For this purpose an array of FLUENT solutions are obtained for a discrete set of pressure differentials that are applied to the models inlet and outlet boundaries. From these solutions, the helium mass flow rates are obtained and water rod in-tube velocities computed. The FLUENT results for the water rod top and bottom sections are provided in Tables 2.1 and 2.2. These results are fitted to a porous media pressure drop model and the flow resistance parameters D and C obtained and reported in Table 2.5. The FLUENT pressure drop results and fitted correlations are graphed in Figures 2.8 and 2.9 for the water rod top and bottom sections respectively. The plots show that the porous media pressure drop closely approaches the FLUENT solution from above in the lower range of velocities and departs with an increasing margin in the higher range of velocities.

The water rods flow hole resistance parameters are then input to the in-channel flow model and an array of FLUENT solutions are obtained for a discrete set of pressure differentials (ΔP_o) applied to the inlet (GE-12/14 bottom fitting hole) and outlet (model top) boundaries. From these solutions, the helium mass flow rates (M_l) are obtained and helium superficial velocities (V) based on channel inside area computed. The ΔP_o vs. V results are then fitted to a porous media pressure drop model and the flow resistance parameters D and C obtained. The fitted parameters are reported in Table 2.5 and pressure drop results are graphed in Figure 2.10. The plot shows that the porous media pressure drop closely approaches the FLUENT solution from above in the lower range of velocities and departs with an increasing margin in the higher range of velocities.

For obtaining the in-cell flow resistance, it is necessary to characterize the contribution of the annulus flow (i.e. path (2) helium mass flow shown in Figure 2.1). For this purpose the annulus flow model is employed to obtain an array of FLUENT solutions for a discrete set of pressure differentials (ΔP_o) applied to the model inlet (bottom) and outlet (top) boundaries. The differential pressures applied to this model are identical to those employed for the parallel flow path (1) in-channel model. From these solutions, the helium mass flow rates (M_2) are obtained. As the in-channel and annulus flows are arrayed in parallel, it follows that the in cell mass flow (M) is the sum of M_1 and M_2. From the in-cell mass flow rates the superficial helium velocities (V) based on cell inside area are computed. The ΔP_o vs. V results are then fitted to a porous media pressure drop model and the flow resistance parameters D and C obtained. The fitted parameters are reported in Table 2.5 and pressure drop results are graphed in Figure 2.11. The plot shows that the porous media pressure drop closely approaches the FLUENT solution from above in the lower range of velocities and departs with an increasing margin in the higher range of velocities.

2.5 Usage Guide for Global Modeling

To address a variety of approaches to HI-STORM global modeling, the flow resistance parameters are made available in several formats. These formats are defined below:

(a) Detailed In-Cell 3-D Model

This model includes a 3-D construction of the fuel basket cell walls. Each fuel storage cell space includes a square fuel channel. The channel-to-cell space is modeled as a fluid gap. For these models, the channel interior space between the MPC bottom and top plenums should be modeled as a porous media region to which the in-channel flow resistance parameters reported in Table 2.5 are applied.

(b) Homogeneous In-Cell 3-D Model

This model includes a 3-D construction of the fuel basket cell walls. The storage cell space is modeled as a continuum with equivalent flow resistance characteristics. For these models, the storage cell interior space between the MPC bottom and top plenums is modeled as a porous media region to which the in-cell flow resistance parameters reported in Table 2.5 are applied.

(c) Homogeneous Basket Model

This model renders the fuel basket cells as a 2-D axisymmetric or a 3-D cylindrical continuum having effective flow resistance properties. For such models, the in-cell flow resistance parameters are mapped from cell square opening area to cell square pitch area. The mapping relationships are defined below:

$$D' = D\left(\frac{A'}{A}\right)$$

$$C' = C\left(\frac{A'}{A}\right)^2$$

where, D' and C' are flow resistance parameters mapped to square pitch area A', and C and D are in-cell flow resistance parameters based on square opening area A. Using the MPC-68 cell opening and pitch data (Section 2.1) the mapped parameters for homogeneous basket models are computed and reported in Table 2.6.

2.6 List of Computer Files

Geometry Pre-processor (Gambit) Files

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10/14/2004  02:21 PM          16,896 wr-bot-pd.xls
10/14/2004  02:24 PM          16,384 wr-top-pd.xls
```

PROPRIETARY INFORMATION REMOVED

Table 2.1: Water Rod Top Flow Resistance Runs

Run No.	ΔP [Pa]	Mass Flow Rate (Mr) [kg/s]	In-Rod Velocity ($V = Mr/(\rho A)$) [m/s]
1	0.02	8.272×10^{-6}	0.02858
2	0.04	1.500×10^{-5}	0.05182
3	0.06	2.090×10^{-5}	0.07221
4	0.08	2.624×10^{-5}	0.09066
5	0.10	3.119×10^{-5}	0.1077
6	0.12	3.584×10^{-5}	0.1238
7	0.14	4.024×10^{-5}	0.1390
8	0.16	4.442×10^{-5}	0.1535
9	0.18	4.844×10^{-5}	0.1673
10	0.20	5.232×10^{-5}	0.1808
Area (A): 0.6648 in^2 (4.288×10^{-4} m^2) Reference helium density (ρ): 0.675 kg/m^3			

Table 2.2: Water Rod Bottom Flow Resistance Runs

Run No.	ΔP [Pa]	Mass Flow Rate (Mr) [kg/s]	In-Rod Velocity (V = Mr/(ρA)) [m/s]
1	0.2	4.611×10^{-6}	0.01593
2	0.4	8.283×10^{-6}	0.02862
3	0.6	1.145×10^{-5}	0.03956
4	0.8	1.430×10^{-5}	0.04940
5	1.0	1.691×10^{-5}	0.05842
6	1.2	1.932×10^{-5}	0.06675
7	1.4	2.163×10^{-5}	0.07473
8	1.6	2.381×10^{-5}	0.08226
9	1.8	2.593×10^{-5}	0.08959
10	2.0	2.788×10^{-5}	0.09632

Area (A): 0.6648 in^2 (4.288×10^{-4} m^2)

Reference helium density (ρ): 0.675 kg/m^3

PROPRIETARY INFORMATION REMOVED

Table 2.3: GE-12/14 In-Channel Flow Resistance Runs

Run No.	ΔP [Pa]	Quarter Symmetric Mass Flow Rate ($M_{1/4}$) [kg/s]	In-Channel Velocity ($V = 4M_{1/4}/(\rho A)$) [m/s]
1	0.5	1.640×10^{-5}	5.407×10^{-3}
2	1.0	3.209×10^{-5}	0.01058
3	1.5	4.729×10^{-5}	0.01559
4	2.0	6.212×10^{-5}	0.02048
5	2.5	7.669×10^{-5}	0.02529
6	3.0	9.105×10^{-5}	0.03002
7	3.5	1.052×10^{-4}	0.03469
8	4.0	1.192×10^{-4}	0.03930
9	4.5	1.331×10^{-4}	0.04389
10	5.0	1.469×10^{-4}	0.04844
Channel Opening: 5.278 in Area (A): 27.857 in^2 (0.017972 m^2) Reference helium density (ρ): 0.675 kg/m^3			

Table 2.4: MPC-68 In-Cell Flow Resistance Runs

Run No.	ΔP [Pa]	Flow Path (1) Mass Flow (M_1) [kg/s]	Flow Path (2) Mass Flow (M_2) [kg/s]	In-Cell Velocity ($V = (M_1+M_2)/(\rho A)$) [m/s]
1	0.5	6.560×10^{-5}	5.526×10^{-5}	7.575×10^{-3}
2	1.0	1.284×10^{-4}	1.105×10^{-4}	0.01497
3	1.5	1.892×10^{-4}	1.656×10^{-4}	0.02224
4	2.0	2.485×10^{-4}	2.208×10^{-4}	0.02941
5	2.5	3.068×10^{-4}	2.759×10^{-4}	0.03652
6	3.0	3.642×10^{-4}	3.309×10^{-4}	0.04356
7	3.5	4.208×10^{-4}	3.859×10^{-4}	0.05056
8	4.0	4.768×10^{-4}	4.408×10^{-4}	0.05751
9	4.5	5.324×10^{-4}	4.958×10^{-4}	0.06444
10	5.0	5.876×10^{-4}	5.506×10^{-4}	0.07133

Cell Opening: 6.053 in

Area (A): 36.639 in^2 (0.023638 m^2)

Reference helium density (ρ): 0.675 kg/m^3

PROPRIETARY INFORMATION REMOVED

Table 2.5: GE-12/14 Flow Resistance Parameters

Flow Model	Velocity Basis	D [m^{-2}]	C [m^{-1}]
Water Rod Top Section	Water rod inside area	7.5×10^4	30
Water Rod Bottom Section	Water rod inside area	8.55×10^5	715
GE-12/14 In-Channel	Channel inside area	7.36×10^5	200
MPC-68 In-Cell	Cell inside area	5.25×10^5	95

PROPRIETARY INFORMATION REMOVED

Table 2.6: Flow Resistance Parameters for Homogeneous Fuel Basket Models

Parameter	Value
D"	$6.035 \times 10^5\ m^{-2}$
C'	$125.5\ m^{-1}$

PROPRIETARY INFORMATION REMOVED

CHAPTER 3.0: PWR FUEL RESISTANCE

In this chapter, the upflow resistance of a limiting PWR fuel assembly (Westinghouse 17x17 OFA) located in an MPC-32 storage cell is obtained. For this purpose, a 3-D CFD model of the fuel assembly is constructed and a pressure drop curve $\Delta P_o(V)$ as a function of helium superficial velocity V is obtained. The pressure drop curve is obtained for the same reference conditions used in Chapter 2.0. The pressure drop curve is fitted to a porous media model of the flow region consistent with the representation in FLUENT, as described in Chapter 2.0. To ensure conservatively bounding pressure drop versus flow rate data are obtained, flow through the guide tubes and instrumentation tube is completely neglected.

3.1 CFD Modeling Data

In Figure 3.1 an elevation view of a Westinghouse 17x17 OFA fuel assembly in an MPC-32 storage cell is presented. Under fuel storage conditions (decay heat generation in the fuel assembly and pressurized helium filling the open spaces in the MPC) helium enters the storage cell from bottom openings (not shown), flows upwards through the fuel assembly to the open space above the top nozzle and exits the storage cell from top openings into the top plenum.

To characterize the storage cell upward flow resistance the storage cell length "L" between top and bottom openings (See Figure 3.1) is modeled in three dimensions on the FLUENT computer program. The pertinent fuel assembly data assembled from both proprietary and open sources in Holtec's possession is provided below:

(Shaded text contains Confidential & Proprietary Information. Do not release to third parties without proprietary safeguards).

Rods Layout:	**17x17 array**
Fuel Rods OD:	**0.360"**
Fuel Rods Pitch:	**0.496"**
Fuel Rods Length:	**153.357"**
Number of Fuel Rods:	**264**

[redacted]

Guide/Instrument Tube OD: **0.474"**

Number of Grids: **11**

[redacted]

Lower Nozzle Height: **2.383"**

[redacted]

It is noted that the number of grids listed above is appropriate for Westinghouse 17x17 Vantage5 fuel assemblies and conservative for Westinghouse 17x17 OFA fuel assemblies. From a hydraulic resistance point of view, the only difference between these two assembly designs is the number of grids, so a conservatively bounding model was constructed.

The MPC-32 storage cell dimensional data [3.1] is summarized below:

Cell opening: 8.79"
Cell pitch: 9.218"
Cell height: 171.75"
(between top & bottom plenums)

The helium properties at reference conditions are the same as given in Section 2.1.

3.2 In-Cell Model

Using the fuel assembly data from Section 3.1, a one-eighth symmetric three-dimensional hydraulic model of the Westinghouse 17x17 OFA fuel assembly is constructed on the FLUENT code. A planar section view through the fuel rods / grids region of this model is shown in Figure 3.2. As shown in Figure 3.2, the bottom horizontal edge and the left diagonal edge are symmetry planes. The guide tubes and instrument tube are assumed to be completely closed to flow.

Both the top of the bottom nozzle and the bottom of the top nozzle are constructed with thick, perforated sections. The perforations in the bottom nozzle are circular, while in the top nozzle the perforations are parallel slots. These two sections are included in the three-dimensional fuel assembly model as porous media, as direct geometry generation would likely be impossible. A source of empirically derived hydraulic resistance data for thick perforated plates [3.2] is used to determine the hydraulic resistance and corresponding inertial resistance factors for these items. The calculated inertial resistance factors are:

Component	Inertial Resistance Factor [m^{-1}]
Bottom Nozzle Perforated Section	2305
Top Nozzle Perforated Section	3376

For conservatism, the fuel assembly model includes the following assumptions:

a) The "feet" in the corners of the bottom nozzle are modeled as larger than actual. This conservatively lowers the area available for flow in the area occupied by these items.
b) The bottom nozzle "skirt" is modeled as thicker than actual, conservatively decreasing the area available for flow within the skirt.
c) The top nozzle "skirt" is modeled as thicker than actual, conservatively decreasing the area available for flow within the skirt.
d) The "flange" at the top of the top nozzle (i.e., the piece engaged by the fuel handling tool) is modeled as thicker than actual, conservatively decreasing the area available for flow within the flange area.

3.3 Flow Resistance Computations

As discussed in this chapter, a three-dimensional FLUENT model is constructed to characterize the flow resistance of an MPC-32 storage cell occupied by a limiting PWR fuel assembly (Westinghouse 17x17 OFA). To model the flow through the cell and fuel assembly, a one-eighth symmetric model of a Westinghouse 17x17 OFA fuel assembly is constructed as shown in Figure 3.2.

Using this MPC cell / fuel assembly model, an array of FLUENT solutions are obtained for a discrete set of pressure differentials (ΔP_o) applied to the inlet (model bottom) and outlet (model top) boundaries. From these solutions, the helium mass flow rates (M) are obtained and helium superficial velocities (V) based on the MPC cell inside area computed. These values are reported in Table 3.1. The ΔP_o vs. V results are then fitted to a porous media pressure drop model and the flow resistance parameters D and C obtained. The fitted parameters are reported in Table 3.2 and pressure drop results are graphed in Figure 3.3. The plot shows the excellent agreement between calculated pressure drop versus superficial velocity data and the fitted parameters.

3.4 Usage Guide for Global Modeling

To address a variety of approaches to HI-STORM global modeling, the flow resistance parameters are made available in two formats as defined below:

a) Detailed 3-D Model

This model includes a 3-D construction of the fuel basket cell walls. For these models, the cell interior space between the MPC bottom and top plenums would be modeled as a porous media region to which cell area based flow resistance parameters, reported in Table 3.2, are applied.

b) Homogeneous Basket Model

This model renders the fuel basket as a 2-D axisymmetric or a 3-D cylindrical continuum having effective flow resistance properties. For such models, the flow resistance parameters are mapped from a cell area basis to a pitch area basis. The mapping relationships are defined in Section 2.5. Using the MPC-32 cell opening and pitch data (Section 3.1) the mapped parameters for homogeneous basket models are computed and reported in Table 3.2.

3.5 List of Computer Files

Geometry Pre-processor (Gambit) Files

Directory of G:\Projects\5014\REPORTS\HI-2043285\PWR

12/15/2004	11:10a	530,579,456	w17v5h.dbs
12/15/2004	11:10a	3,783,265	w17v5h.jou
12/15/2004	11:31a	237,729,504	w17v5h.msh
12/15/2004	11:37a	43,067	w17v5h.trn

CFD Solver (FLUENT) Files

Directory of G:\Projects\5014\REPORTS\HI-2043285\PWR

12/15/2004	12:46p	141,205,828	w17v5h-1.cas
12/15/2004	12:46p	153,388,228	w17v5h-1.dat
12/15/2004	01:30p	141,205,038	w17v5h-2.cas
12/15/2004	01:30p	153,387,936	w17v5h-2.dat
12/15/2004	02:00p	141,205,040	w17v5h-3.cas
12/15/2004	02:01p	153,387,936	w17v5h-3.dat
12/16/2004	10:48a	141,205,043	w17v5h-4.cas
12/16/2004	10:48a	153,387,840	w17v5h-4.dat
12/16/2004	10:19a	141,205,039	w17v5h-5.cas
12/16/2004	10:19a	153,387,744	w17v5h-5.dat
12/16/2004	11:14a	141,205,043	w17v5h-6.cas
12/16/2004	11:14a	153,387,744	w17v5h-6.dat
12/16/2004	11:44a	141,205,045	w17v5h-7.cas
12/16/2004	11:44a	153,387,648	w17v5h-7.dat
12/16/2004	12:12p	141,205,043	w17v5h-8.cas
12/16/2004	12:12p	153,387,552	w17v5h-8.dat
12/16/2004	01:34p	141,205,045	w17v5h-9.cas
12/16/2004	01:34p	153,387,552	w17v5h-9.dat
12/16/2004	02:07p	141,205,043	w17v5h-10.cas
12/16/2004	02:07p	153,387,456	w17v5h-10.dat

Miscellaneous Calculations (Mathcad and Excel) Files

Directory of G:\Projects\5014\REPORTS\HI-2043285\PWR

12/22/2004	03:57p	18,669	nozzperf.mcd
12/16/2004	02:57p	22,016	curvefit.xls
12/22/2004	03:42p	11,025	factors.mcd

PROPRIETARY INFORMATION REMOVED

Table 3.1: MPC-32 In-Cell Flow Resistance Runs

Run No.	ΔP [Pa]	One-Eight Symmetric Mass Flow Rate [kg/s]	Whole-Cell Mass Flow Rate [kg/s]	In-Cell Velocity ($V = M_2/(\rho A)$) [m/s]
1	0.5	2.506×10^{-5}	2.005×10^{-4}	5.958×10^{-3}
2	1.0	4.970×10^{-5}	3.976×10^{-4}	1.182×10^{-2}
3	1.5	7.404×10^{-5}	5.923×10^{-4}	1.760×10^{-2}
4	2.0	9.812×10^{-5}	7.850×10^{-4}	2.333×10^{-2}
5	2.5	1.220×10^{-4}	9.760×10^{-4}	2.901×10^{-2}
6	3.0	1.456×10^{-4}	1.165×10^{-3}	3.462×10^{-2}
7	3.5	1.690×10^{-4}	1.352×10^{-3}	4.018×10^{-2}
8	4.0	1.923×10^{-4}	1.538×10^{-3}	4.572×10^{-2}
9	4.5	2.154×10^{-4}	1.723×10^{-3}	5.121×10^{-2}
10	5.0	2.383×10^{-4}	1.906×10^{-3}	5.666×10^{-2}

Cell Opening: 8.79 in

Area (A): 77.264 in^2 (0.049848 m^2)

Reference helium density (ρ): 0.675 kg/m^3

PROPRIETARY INFORMATION REMOVED

Table 3.2: MPC-32 Flow Resistance Parameters

Flow Model	Velocity Basis	D [m^{-2}]	C [m^{-1}]
Detailed 3-D	Cell Area	673003	51.8
Homogeneous	Pitch Area	740138	62.7

PROPRIETARY INFORMATION REMOVED

CHAPTER 4.0: REFERENCES[1]

[1.1] "FLUENT 6.1 User's Guide", February 2003, Fluent Inc., 10 Cavendish Court, Lebanon NH-03766.

[2.1] "Handbook of Heat Transfer", Rohsenow, W.M., and Hartnett, J.P., McGraw Hill Book Company, NY (1973).

[2.2] "Engineering Thermodynamics", Balzhiser, R.E., and Samuels, M.R., Prentice Hall, Inc., (1977).

[2.3] "MPC-68/68F/68FF Fuel Basket", Holtec Drawing 3928, Revision 5.

[3.1] "MPC-32 Fuel Basket Assembly," Holtec Drawing 3927, Revision 6.

[3.2] "Handbook of Hydraulic Resistance – Coefficients of Local Resistance and Friction," I.E. Idel'Chik, NTIS Document AEC-TR-6630, 1960.

[1] The revision status of Holtec documents cited above is subject to updates. The document will be revised if a revision to any of the above references materially affects the instructions, results, analyses or conclusions contained in this document. Otherwise a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supercede the revision numbers cited above. The Holtec project manager bears the undivided responsibility to ensure that there is no intra-document conflict with respect to the information contained in any Holtec-generated on a safety related project. The latest document revision produced by Holtec International in a safety-significant project is readily available from the company's computerized databases.

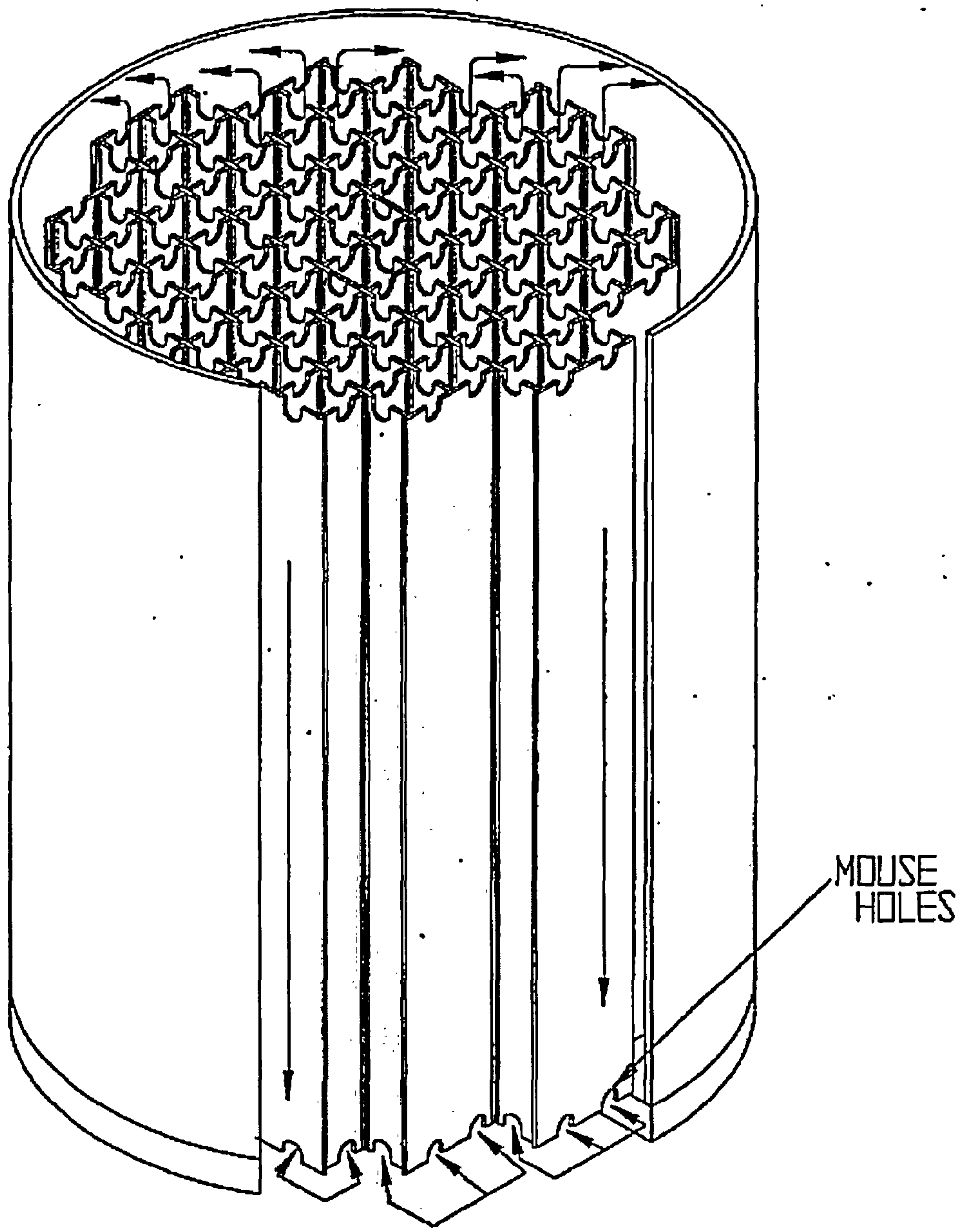

FIGURE 1.1: THERMOSIPHON ACTION IN AN MPC-68 CANISTER

PROPRIETARY INFORMATION REMOVED

FIGURE 2.1: OUTLINE OF A CHANNELED GE10x10 FUEL ASSEMBLY IN AN MPC-68 STORAGE CELL

PROPRIETARY INFORMATION REMOVED

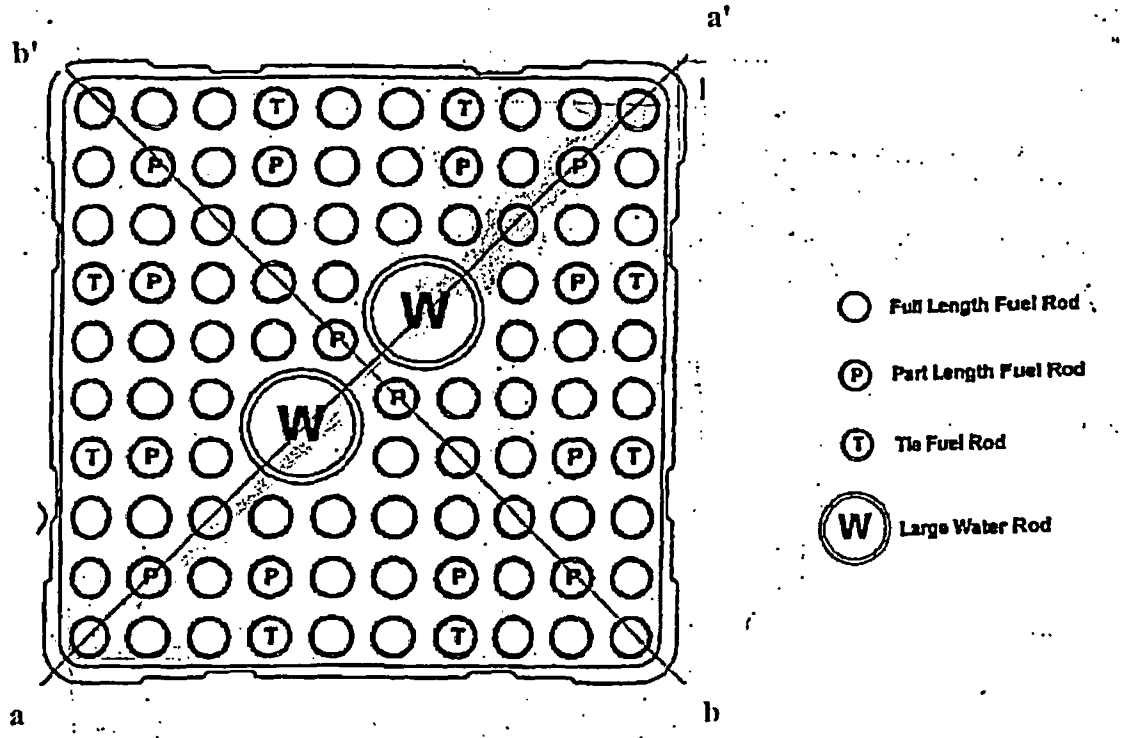

FIGURE 2.2: PLANAR LAYOUT OF A GE-12/14 ASSEMBLY

FIGURE 2.3: DIMENSIONED SKETCH OF A GE12/14 WATER ROD

PROPRIETARY INFORMATION REMOVED

FIGURE 2.4: WATER ROD BOTTOM SECTION FLOW MODEL

PROPRIETARY INFORMATION REMOVED

FIGURE 2.5: WATER ROD TOP SECTION FLOW MODEL

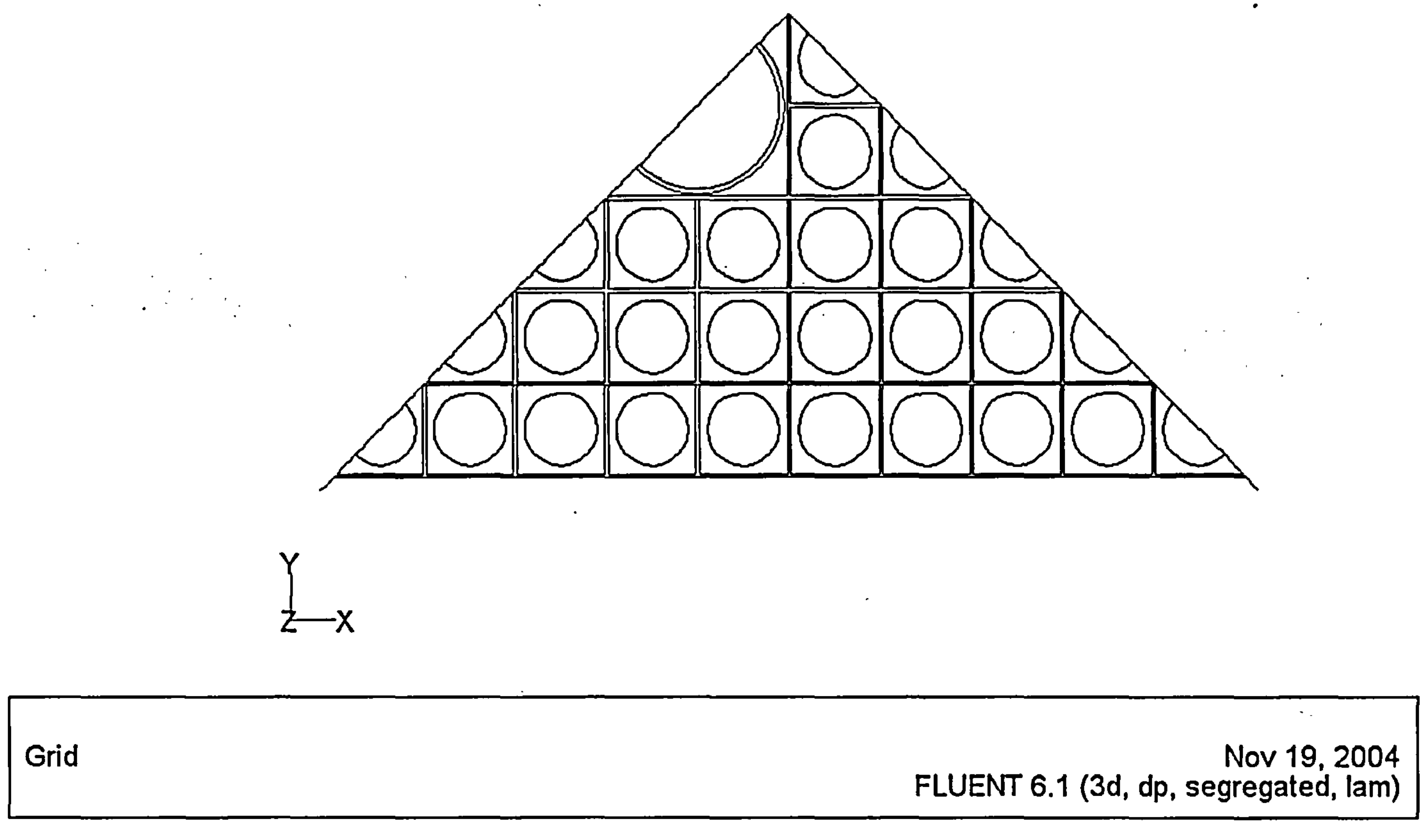

FIGURE 2.6: PLANAR SECTION OF THE GE-12/14 QUARTER SYMMETRY MODEL

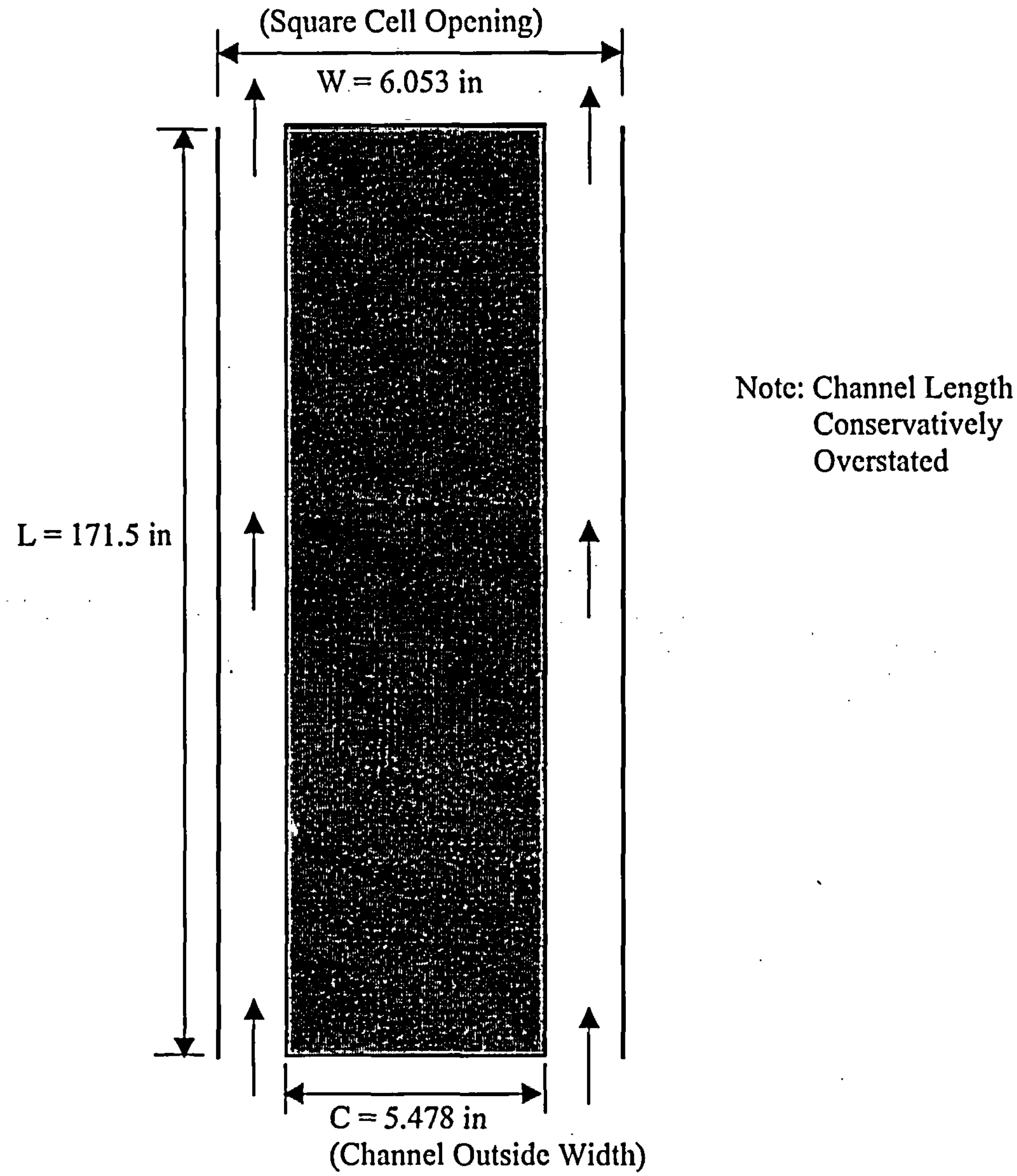

FIGURE 2.7: GE-12/14 CHANNEL-TO-CELL GAP FLOW MODEL

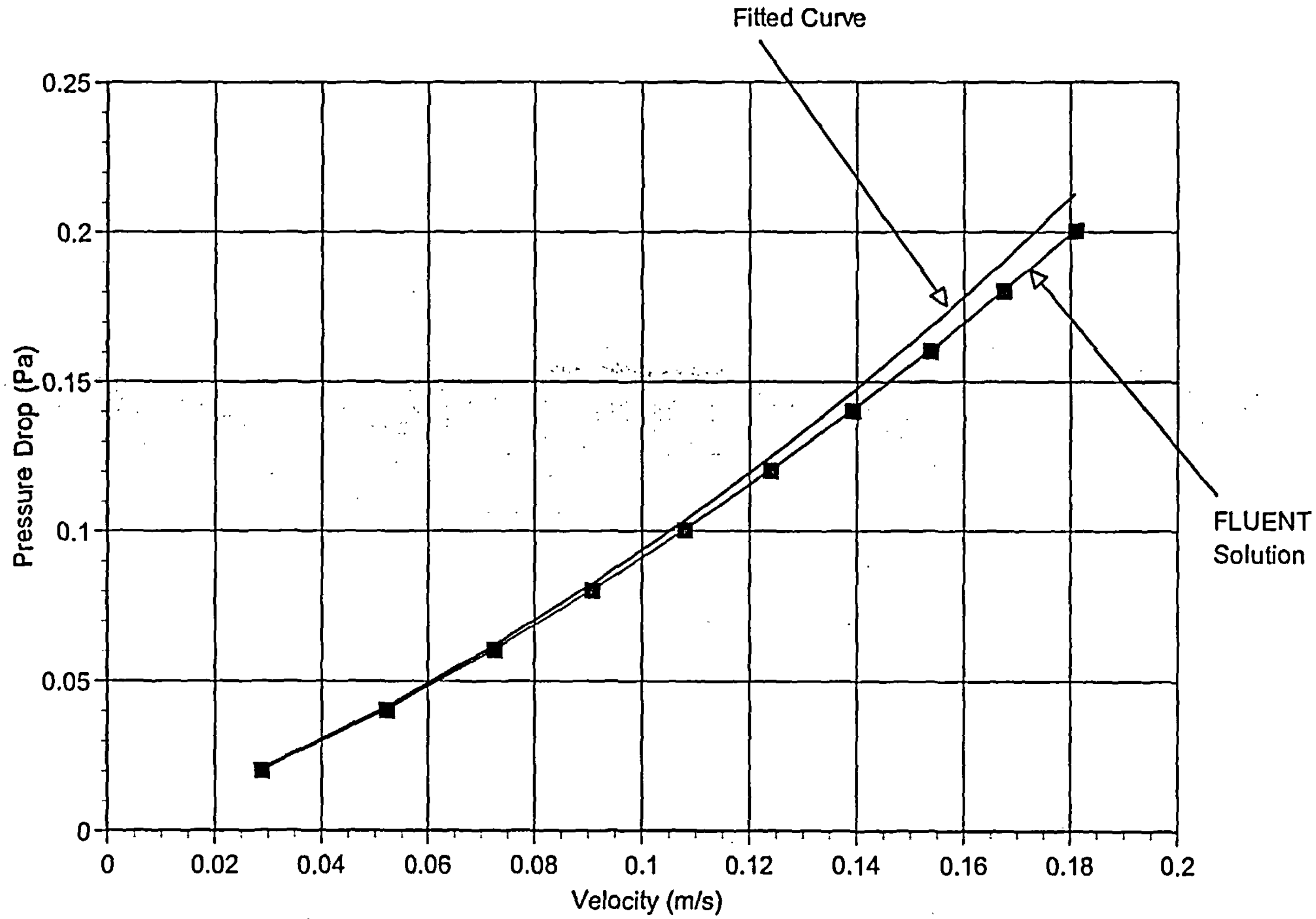

FIGURE 2.8: WATER ROD TOP ZONE PRESSURE DROP CURVE

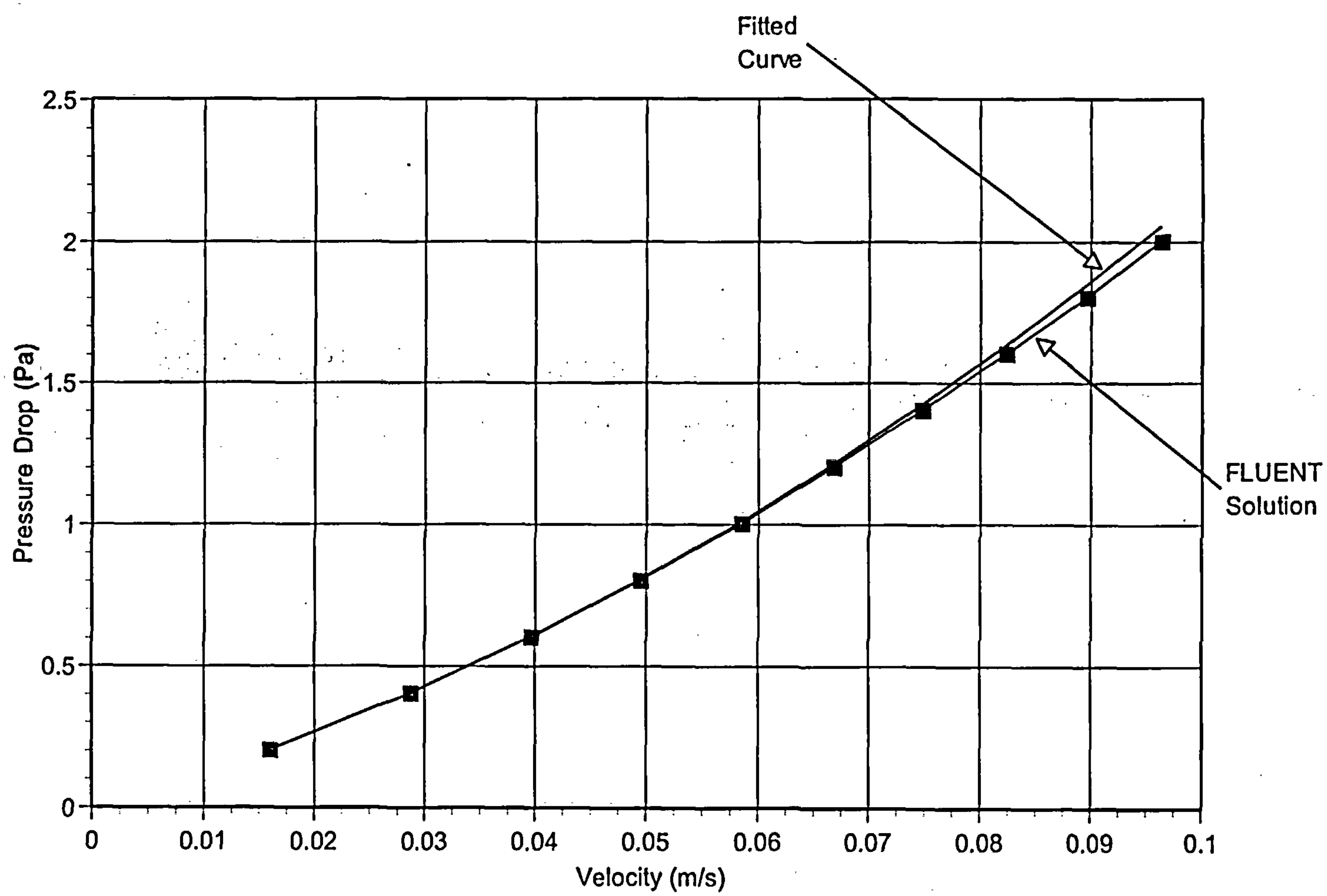

FIGURE 2.9: WATER ROD BOTTOM ZONE PRESSURE DROP CURVE

PROPRIETARY INFORMATION REMOVED

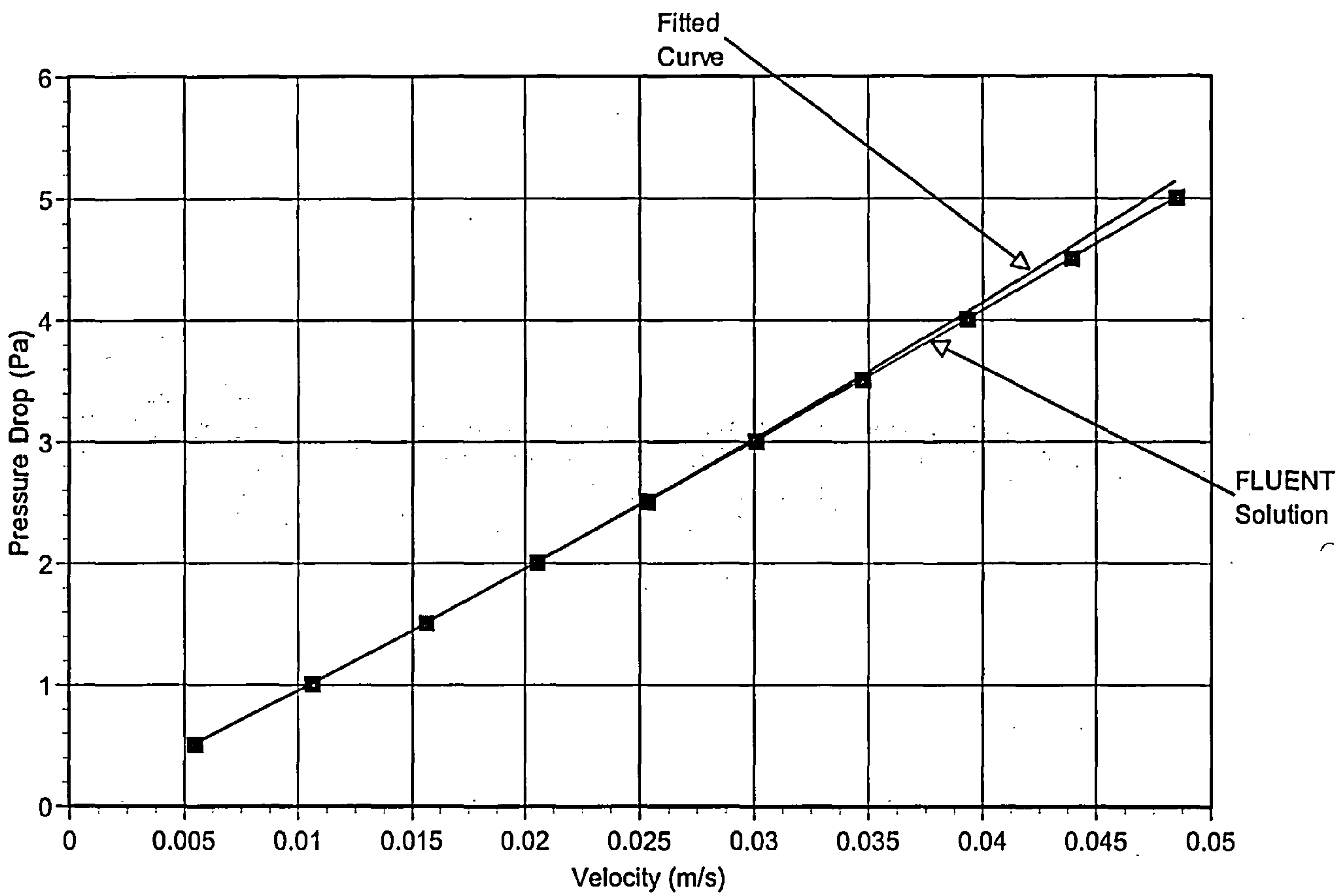

FIGURE 2.10: GE12/14 IN-CHANNEL PRESSURE DROP CURVE

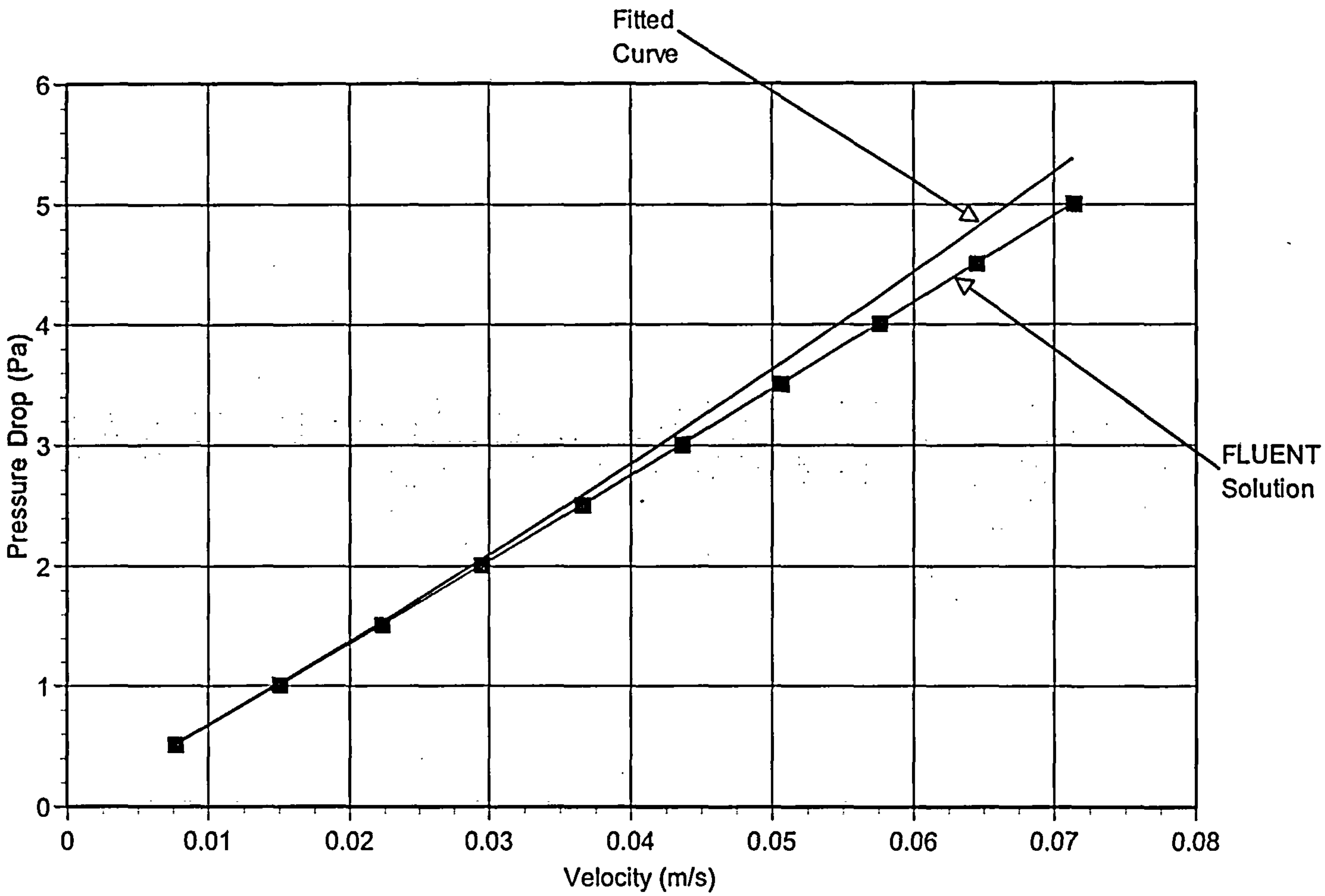

FIGURE 2.11: MPC-68 IN-CELL PRESSURE DROP CURVE

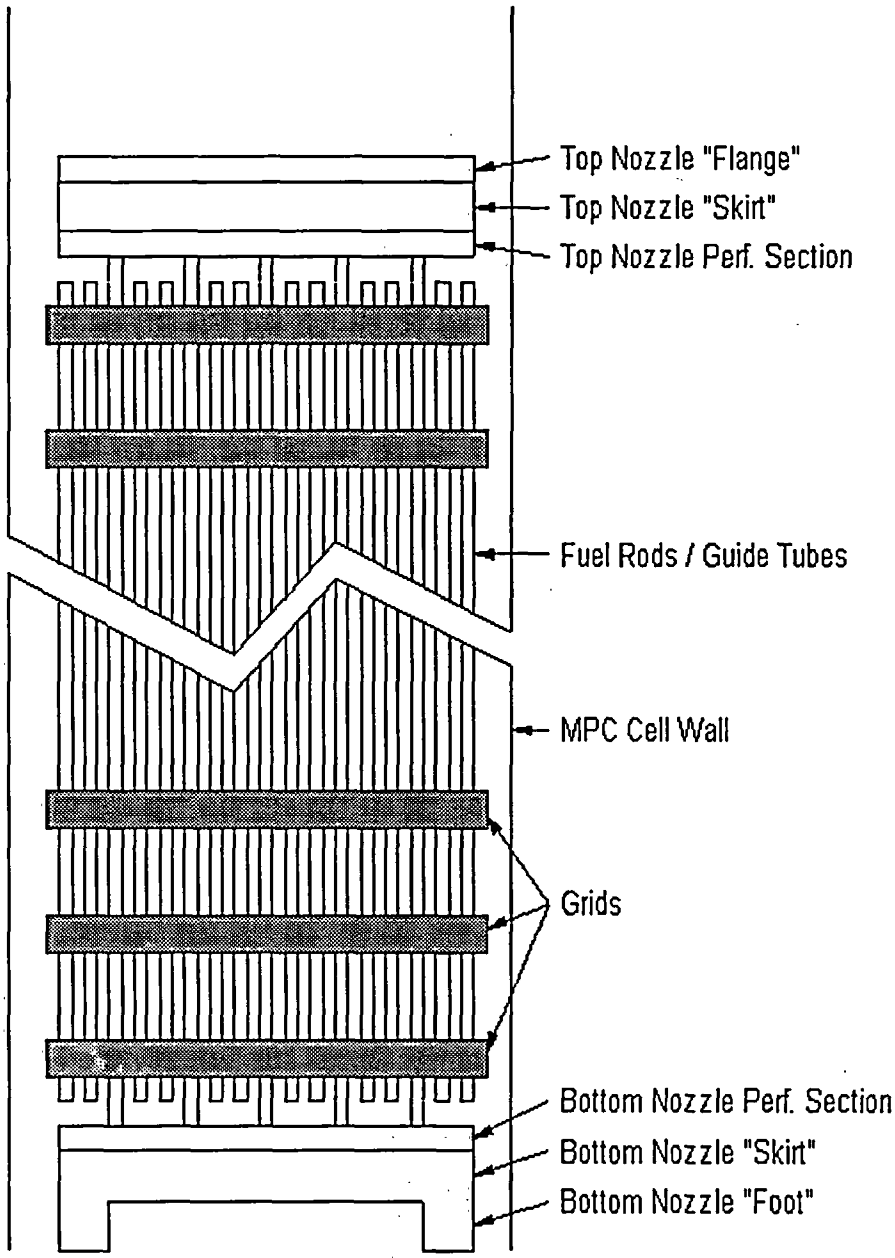

Figure 3.1: Schematic of Westinghouse 17x17 OFA/Vantage Fuel Assembly

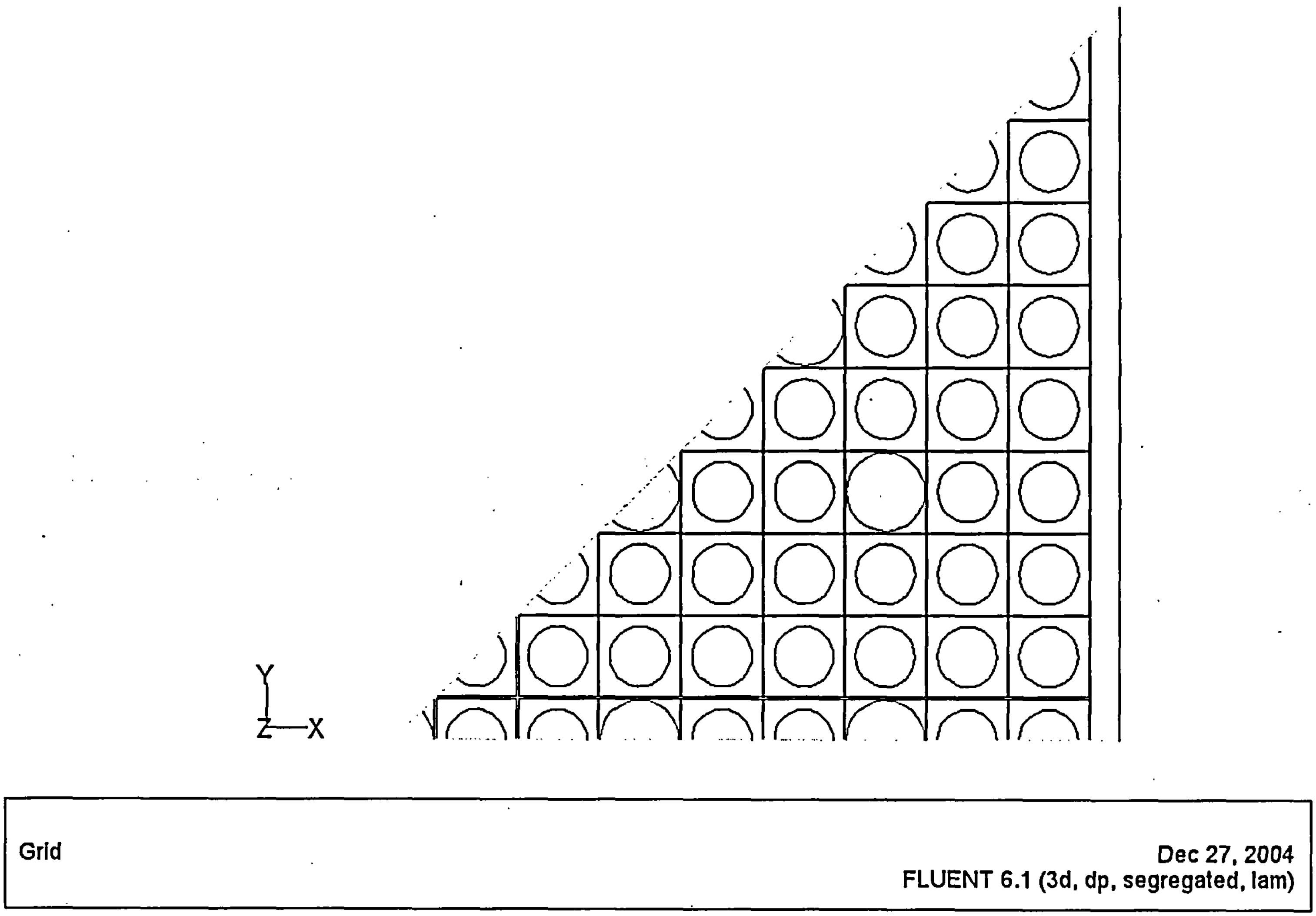

Figure 3.2: Planar Section of 1/8-Symmetric FLUENT Model of Westinghouse 17x17 OFA/Vantage Fuel Assembly
(View through rods, grid and nozzles not shown)

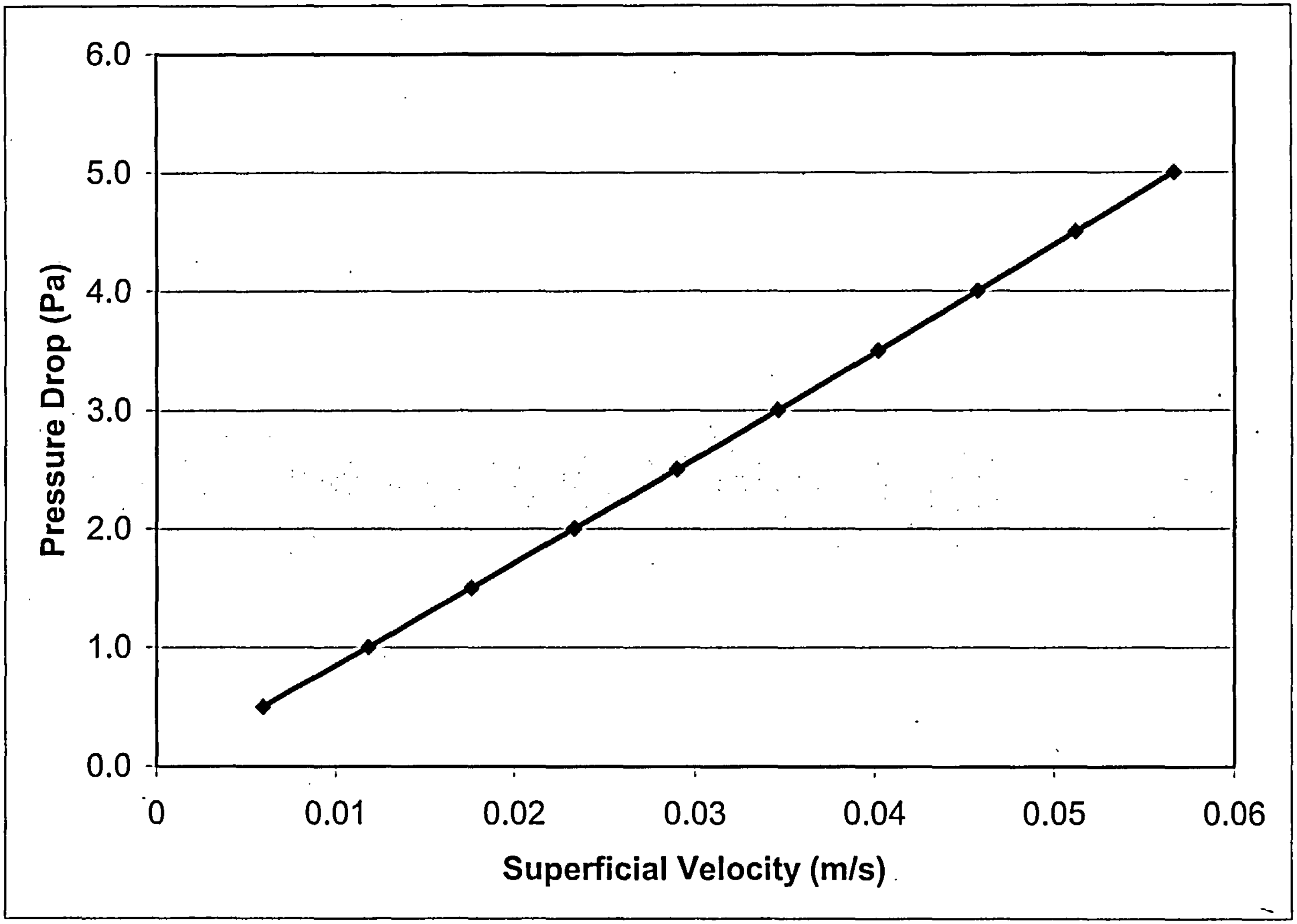

Figure 3.3: Pressure Drop versus Superficial Velocity
(Points are calculated using FLUENT, Line is curve fitted parameters)

HOLTEC APPROVED COMPUTER PROGRAM LIST

(Total No. of Pages = 5)

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 73 September 9, 2004	
PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
ANSYS (A)	5.7,7.0	JZ, ER, PK, CWB, SPA, AIS, IR, SP, AK, SJ, RW, VRP	Windows		
AIRCOOL	5.2I, 6.1		Windows		
BACKFILL	2.0		DOS/ Windows		
BONAMI (Scale)	4.3, 4.4		Windows		
BULKTEM	3.0		DOS/ Windows		
CASMO-4 (A)	1.13.04 (UNIX), 2.05.03 (WINDOWS)	ERD, SPA, DMM, KC, ST,VJB	UNIX/ Windows	Version 1.13.04 should not be used for new projects and should only be used when necessary for additional calculations on previous projects. The user should refer to the error notice documented in c4ser.04-results.pdf located in \generic\library\ nuclear\error notices\ concerning the use of version 1.13.04. Library N should be used with version 2.05.03 for all new reports issued after June 1st, 2003. Revisions to reports issued prior to June 1st, 2003 may continue to use the old Library L.	
CASMO-3 (A)	4.4, 4.7	ERD, SPA, DMM, KC, ST	UNIX		
CELLDAN	4.4.1		Windows		
CHANBP6 (A)	1.0	SJ, PK, CWB, AIS, SP,AK	DOS/Windows		
CHAP08 (CHAPLS10)	1.0		Windows		
CONPRO	1.0		DOS/Windows		
CORRE	1.3		DOS/Windows		
DECAY	1.4, 1.5		DOS/Windows		
DÉCOR	1.0		DOS/Windows		

PROPRIETARY INFORMATION REMOVED

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 73 September 9, 2004	
PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
DR.BEAMPRO	1.0.5		Windows		
DR.FRAME	2.0		Windows		
DYNAMO (A)	2.51	AIS, SP, CWB, PK, SJ	DOS/Windows	Personnel qualified to use MR216 are automatically qualified to use DYNAMO.	
DYNAPOST	2.0		DOS/Windows		
FIMPACT	1.0		DOS/Windows		
FLUENT (A)	4.32, 4.56, 6.1.18	ER, IR, DMM, SPA	Windows	Do not use porous medium with zero velocity.	6.1.18
FTLOAD	1.4		DOS		
GENEQ	1.3		DOS		
HXFLOW	1.0		DOS/Windows		
INSYST	2.01		Windows		
KENO-5A (A)	4.3, 4.4	ERD, SPA, DMM, KC, ST,VJB	Windows		
LONGOR	1.0		DOS/Windows		
LNSMTH2	1.0		DOS/Windows		
LS-DYNA3D (A)	936, 940, 950, 960, 970	JZ, AIS, SPA, SP, KPS,VRP	Windows		
MAXDISP8	1.8		DOS/Windows		
MAXDIS16	1.0		DOS/Windows		
MCNP (A)	4A, 4B	ERD, SPA, KC,ST,DMM, VJB, MAP	Windows/ UNIX	CASMO-4 Lumped Fission Products (IDs 401 and 402) and Isotope Pm148M (ID 61248) can be modeled in MCNP 4A using the cross sections documented in HI-2033031. Use of these cross sections is restricted to MCNP 4A, and to material specifications in atom densities.	
MASSINV	1.4, 1.5, 2.1		DOS/Windows		
MR2	1.7	AIS, SP, CWB, PK, SJ	DOS/Windows	For use in wet storage analysis only.	

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 73 September 9, 2004	
PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
MR216 (A)	1.0, 2.0, 2.2,2.4	AIS, SP, CWB, PK, SJ,AK	DOS/Windows	Versions 2.2 and 2.4 for use in dry storage analyses only. Use DYNAMO for liquefaction problems.	
MSREFINE	1.2,1.3, 2.1		DOS/Windows		
MULPOOLD	2.1		DOS/Windows		
MULTI1	1.3, 1.4, 1.5, 1.54, 1.55		Windows		
NITAWL (Scale)	4.3, 4.4		Windows		
NASTRAN DESKTOP (WORKING MODEL)	6.2, 2001,6.4,2002, 2003,2004		Windows		
ONEPOOL	1.4.1, 1.5, 1.6		DOS/Windows		
ORIGENS (Scale)	4.3, 4.4		Windows		
PD16	1.1, 1.0,2.1		Windows		
PREDYNA1	1.5, 1.4		DOS/Windows		
PREMULT8	1.0		DOS/Windows		
PRESPRG8	1.0		DOS/Windows		
PSD1	1.0		DOS/Windows		
QAD	CGGP		DOS/Windows		
SAS2H (Scale)	4.3, 4.4		Windows		
SFMR2A	1.0		DOS/Windows		
SHAPEBUILDER	3.0		DOS/Windows		
SIFATIG	1.0		DOS/Windows		

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 73 September 9, 2004	
PROGRAM (Category)	VERSION	CERTIFIED USERS	OPERATING SYSTEM	REMARKS	CODE USED
SOLIDWORKS	2001PLUS, 2003		DOS/Windows	This program may be used to calculate Weight, Volume, Centroid and Moment of Inertia. As a precaution, user should avoid keeping more than one drawing files open at any given time during a Solidworks session. If there is a need for multiples drawing files to be open at once, user should ensure that the part names for all open files are uniquely named (i.e. no two parts have the same name.)	
SPG16	1.0, 2.0, 3.0		DOS/Windows		
SHAKE2000	1.1.0, 1.4.0		DOS/Windows		
STARDYNE (A)	4.4, 4.5	SP	Windows		
STER	5.04		Windows		
TBOIL	1.7, 1.9		DOS/Windows	See HI-92832 for restriction on v1.7.	
THERPOOL	1.2, 1.2A		DOS/Windows		
TRIEL	2.0		DOS/Windows		
VERSUP	1.0		DOS		
VIB1DOF	1.0		DOS/Windows		

PROPRIETARY INFORMATION REMOVED

HOLTEC APPROVED COMPUTER PROGRAM LIST				REV. 73 September 9, 2004	
PROGRAM (Category)	**VERSION**	**CERTIFIED USERS**	**OPERATING SYSTEM**	**REMARKS**	**CODE USED**
VMCHANGE	1.4, 1.3		Windows		
WEIGHT	1.0		Windows		

NOTES:

1. XXXX = ALPHANUMERIC COMBINATION
2. GENERAL PURPOSES UTILITY CODES (MATHCAD, EXCEL, ETC.) MAYBE USED ANYTIME.

ATTACHMENT 1

GE-12/14 Bundle Drawings

CONFIDENTIAL & PROPRIETARY INFORMATION

THIRD PARTY PROPRIETARY DATA

DO NOT RELEASE TO OUTSIDE PARTIES

PROPRIETARY INFORMATION REMOVED