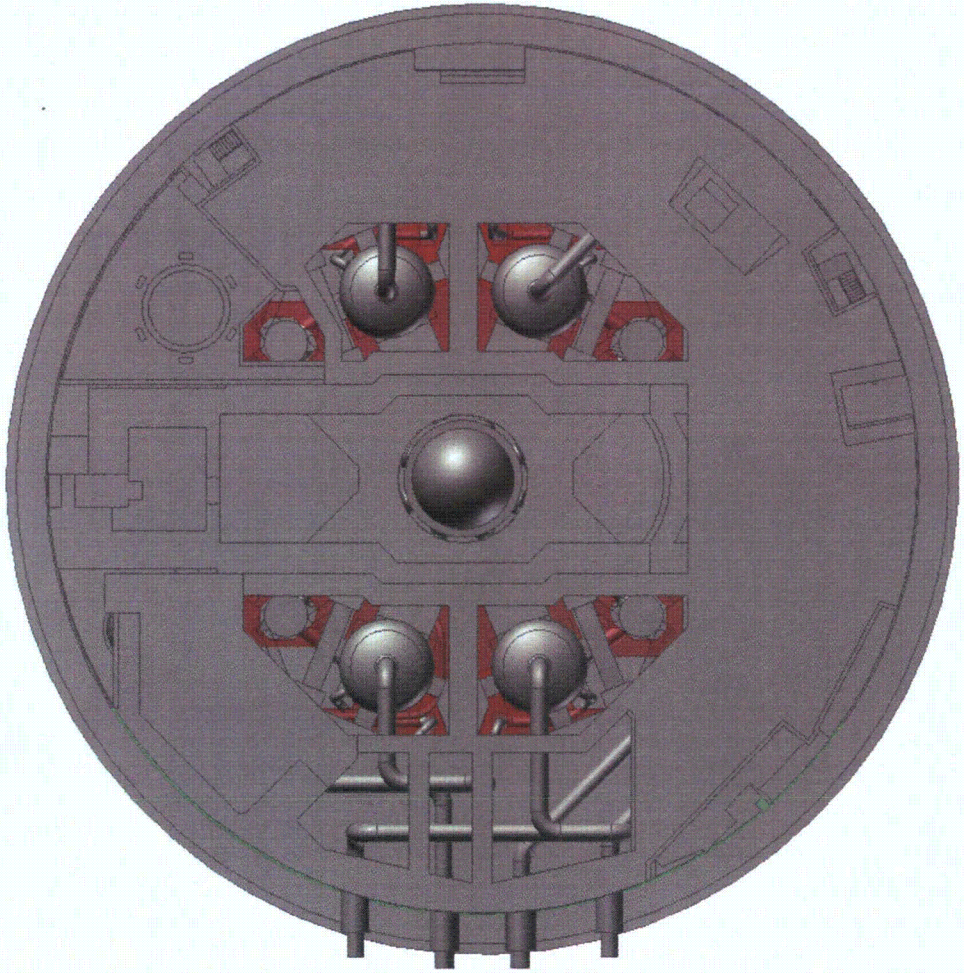


Figure 3.e.1-1 – Plan view of Comanche Peak upper containment CAD model

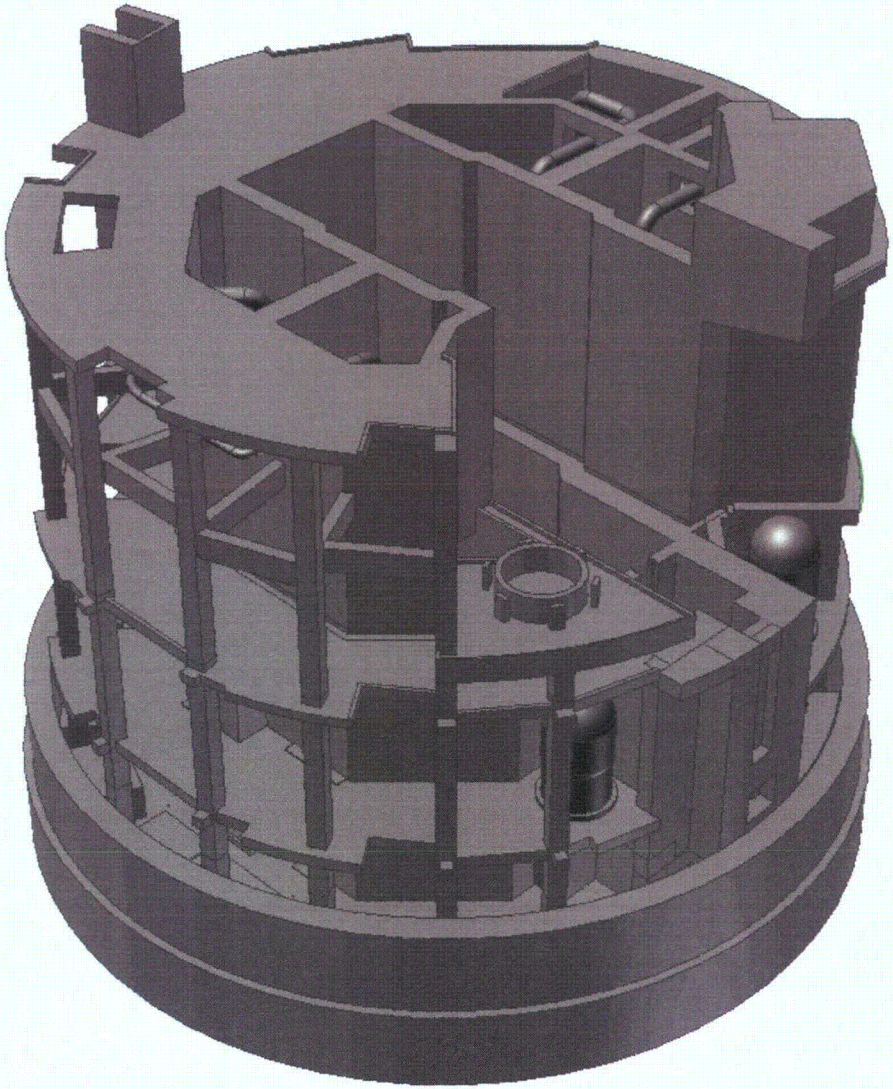


Figure 3.e.1-2 – Isometric view of area outside secondary shield wall

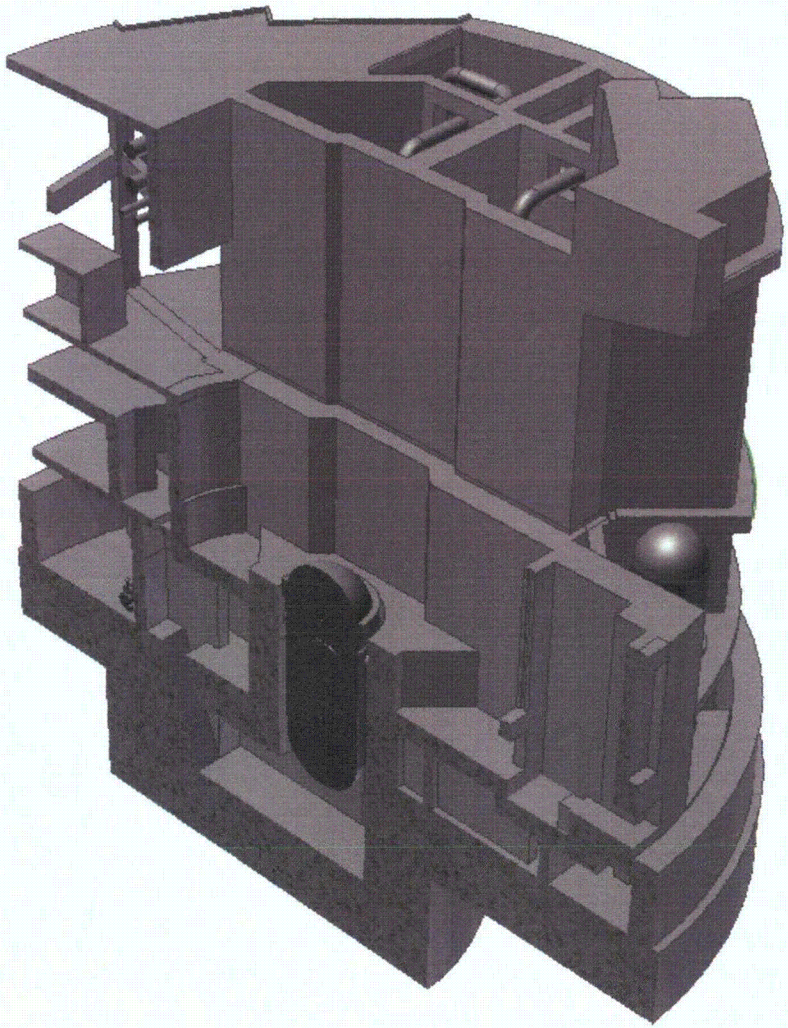


Figure 3.e.1-3 – Cross-section View 1 of containment building

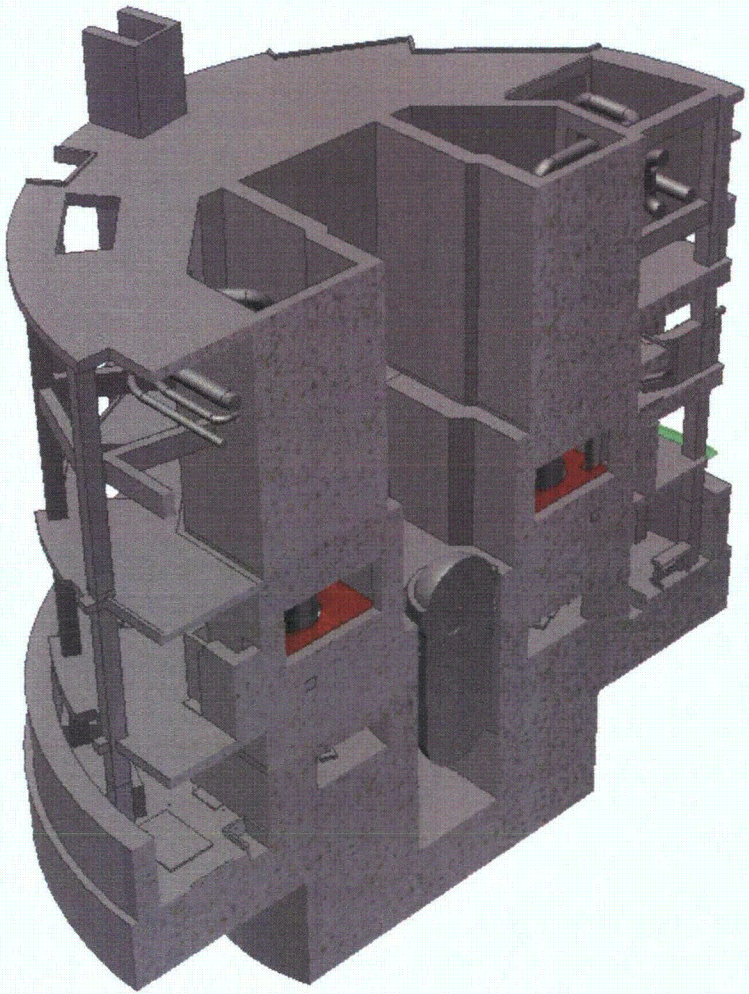


Figure 3.e.1-4 – Cross-section View 2 of containment building

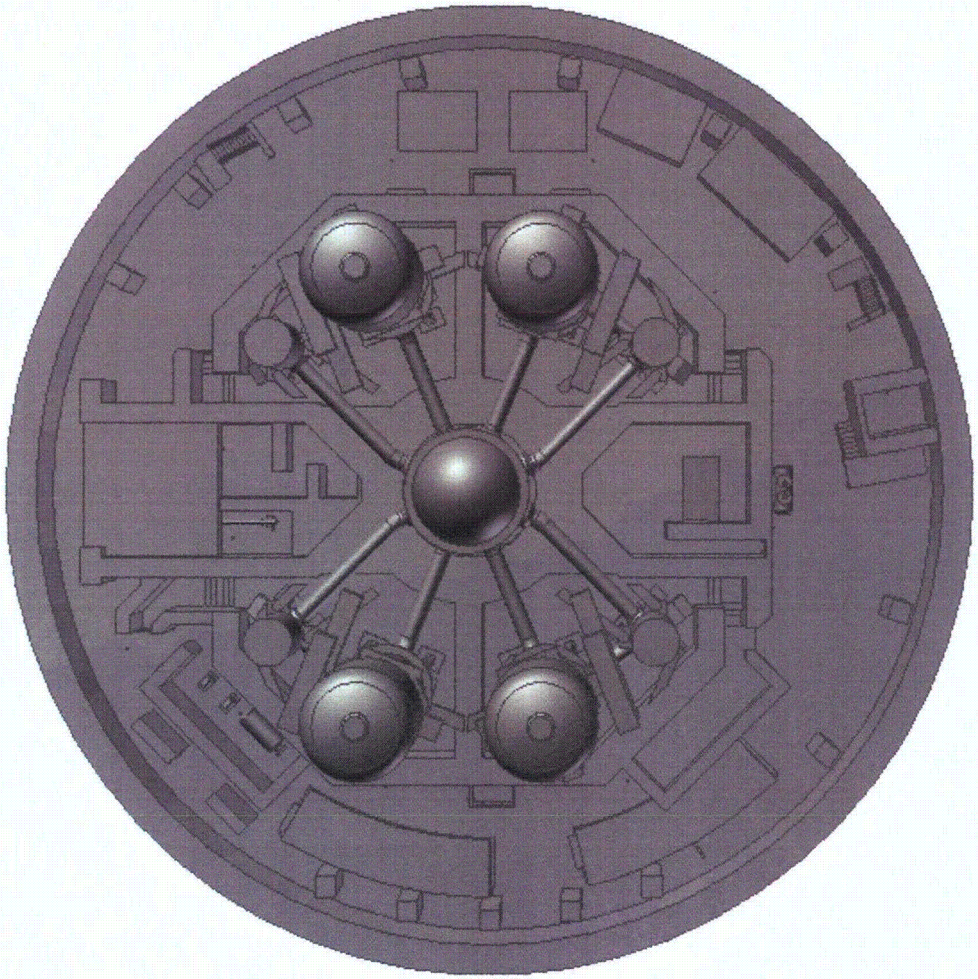


Figure 3.e.1-5 – Plan view of Comanche Peak lower containment CAD model

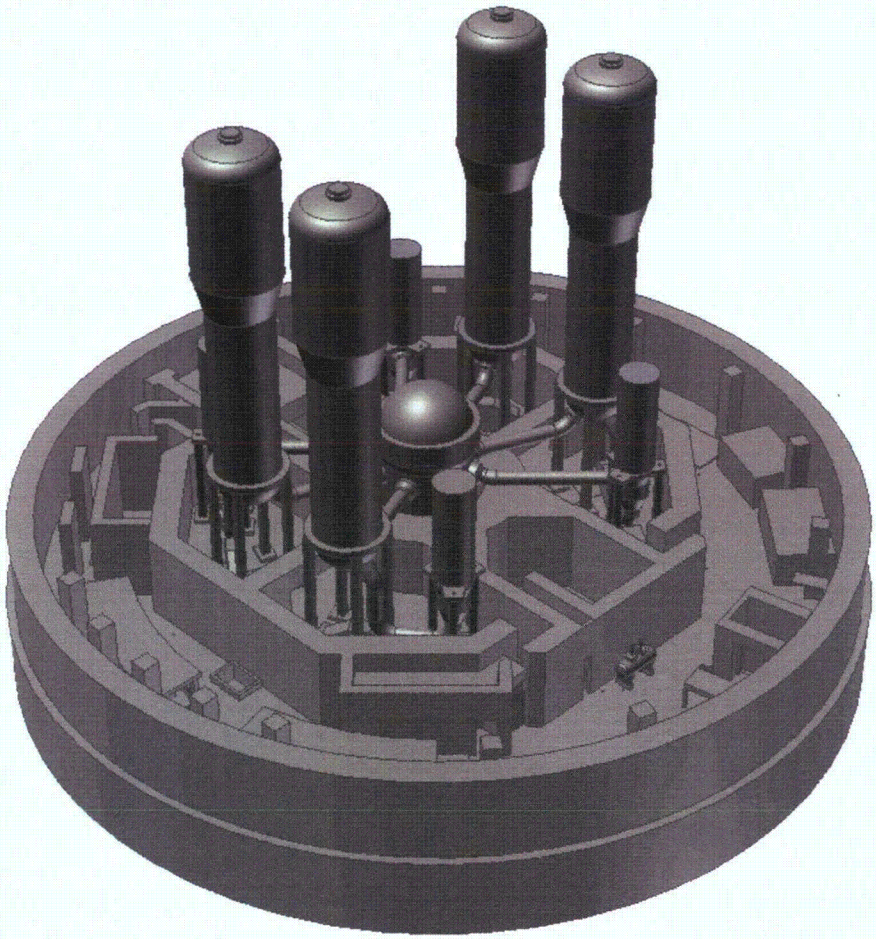


Figure 3.e.1-6 – Southwest isometric view of Comanche Peak lower containment CAD model

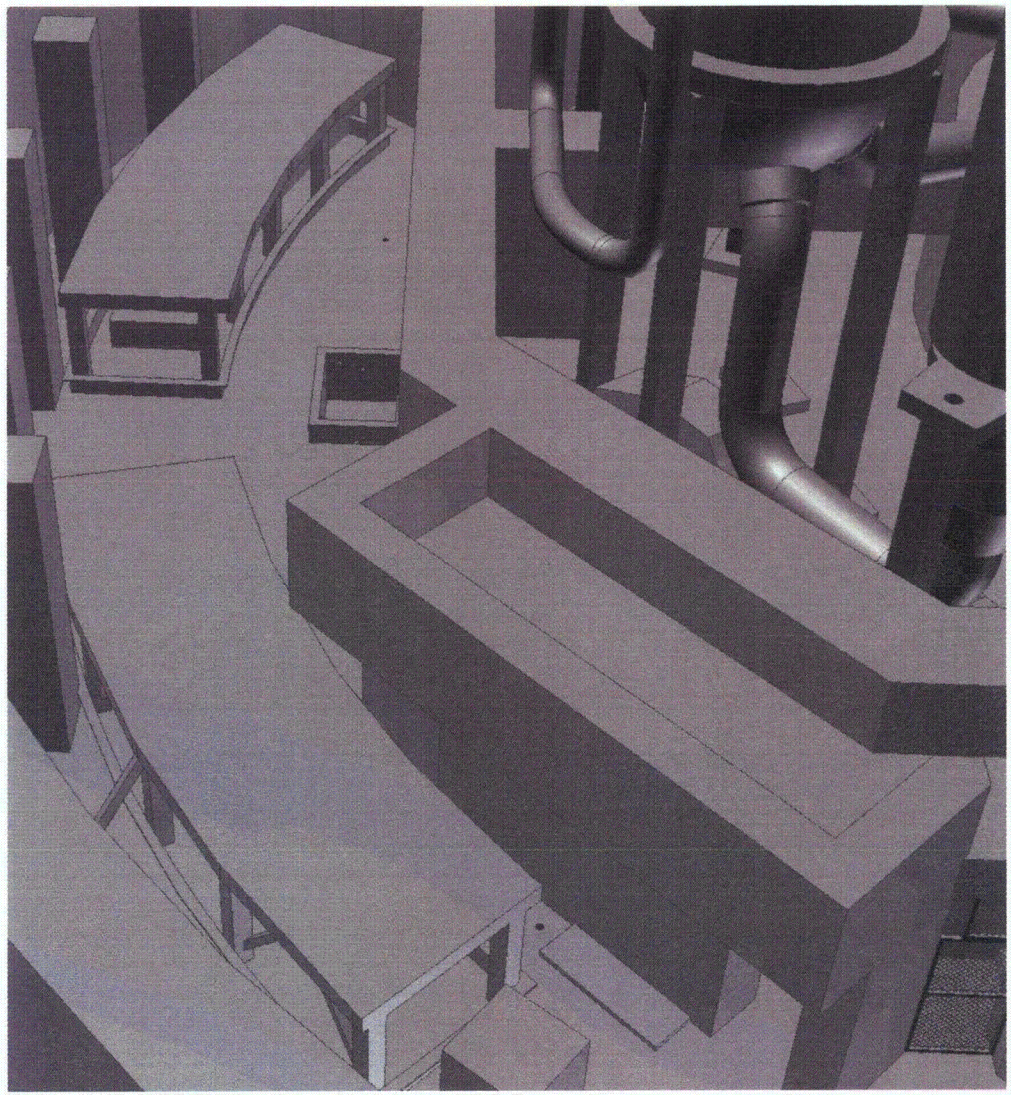
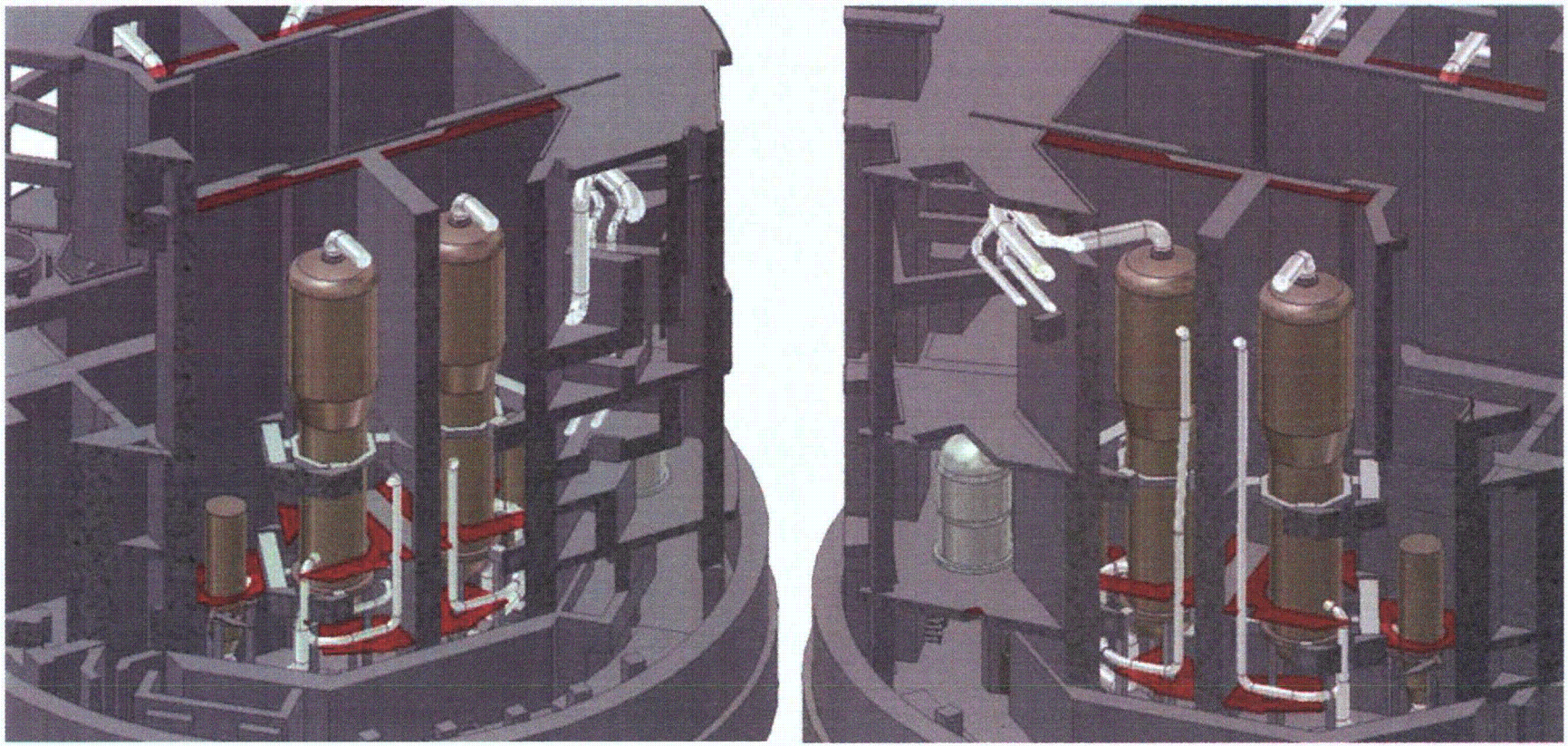


Figure 3.e.1-7 – Close-up of sumps (outside secondary shield wall)



LOOPS 1 & 4 LOOPS 2 & 3

Figure 3.e.1.1-1 – Isometric view of grating in RCS loop rooms

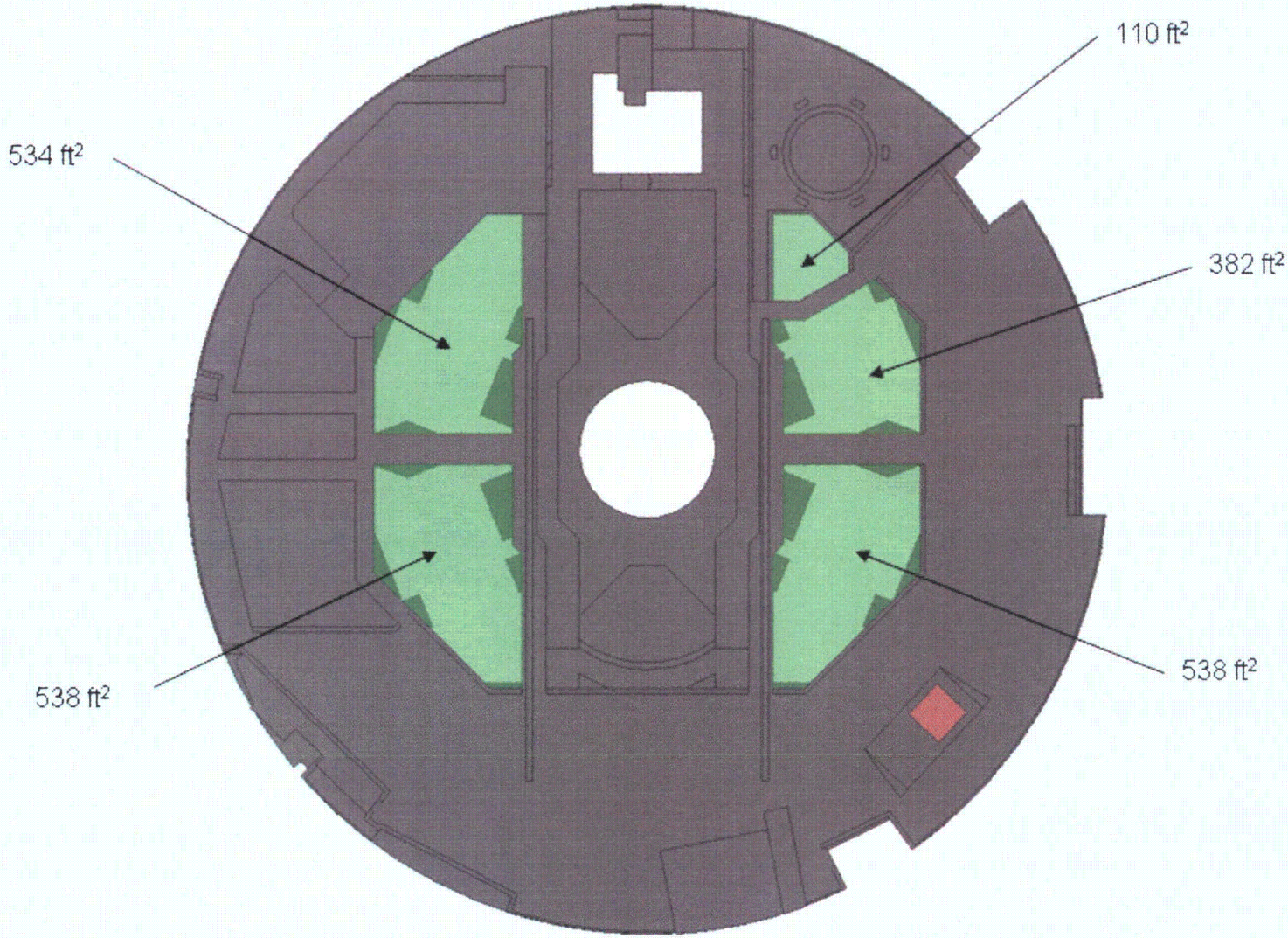


Figure 3.e.1.1-2 – RCS loop room areas

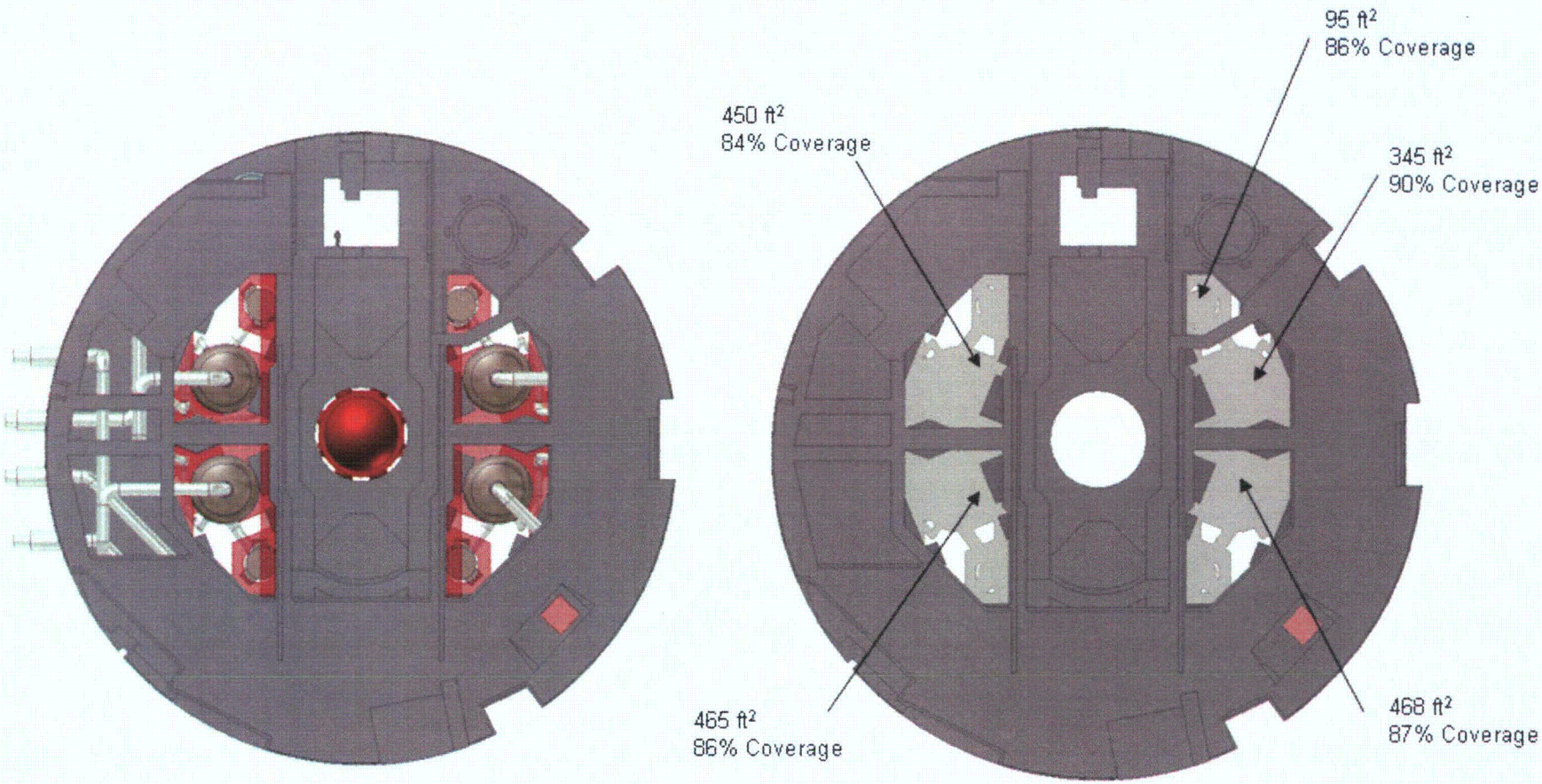


Figure 3.e.1.1-3 – RCS loop room grated areas

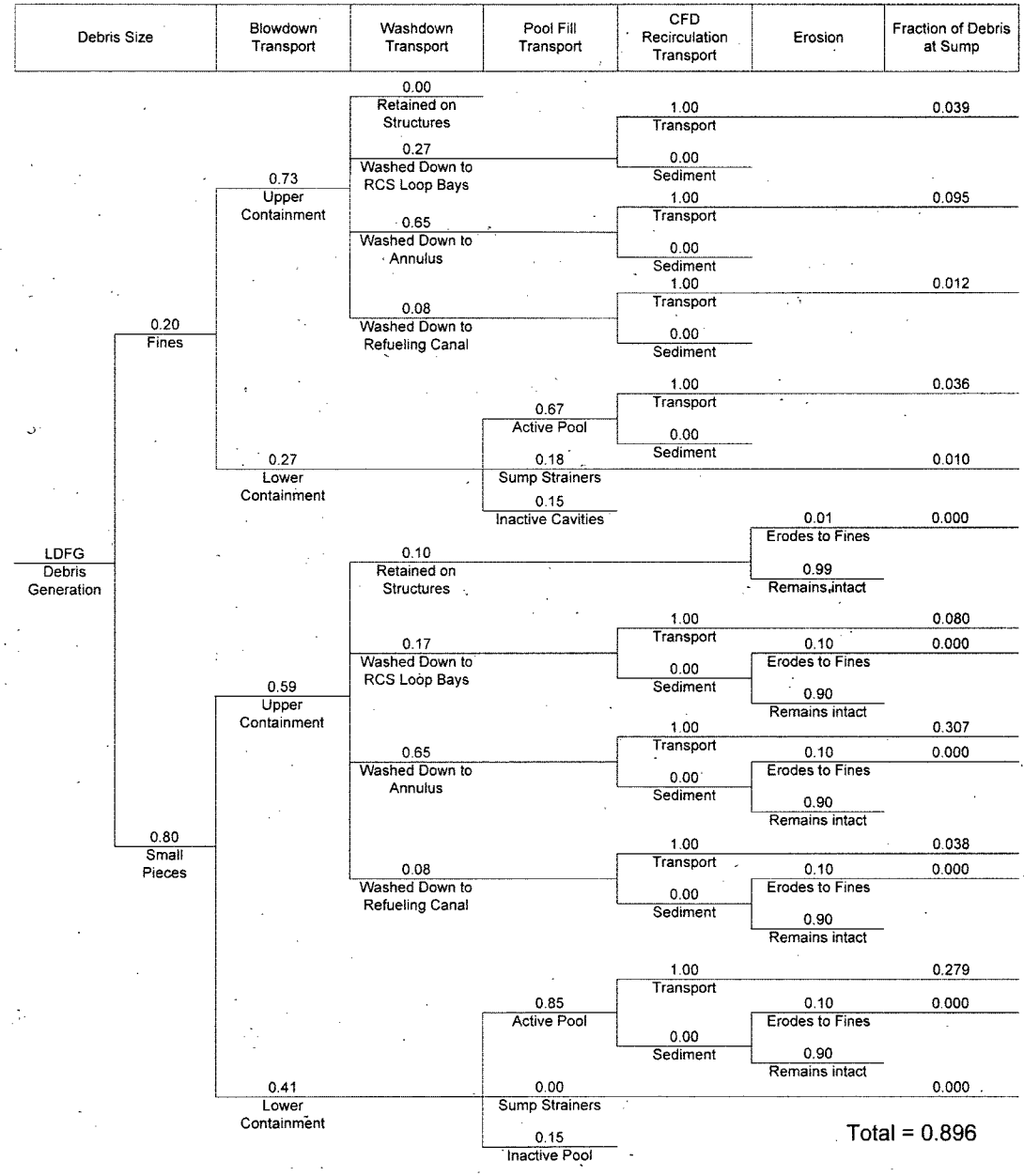


Figure 3.e.1.1-4 – Combined fiberglass logic trees with existing transport fractions

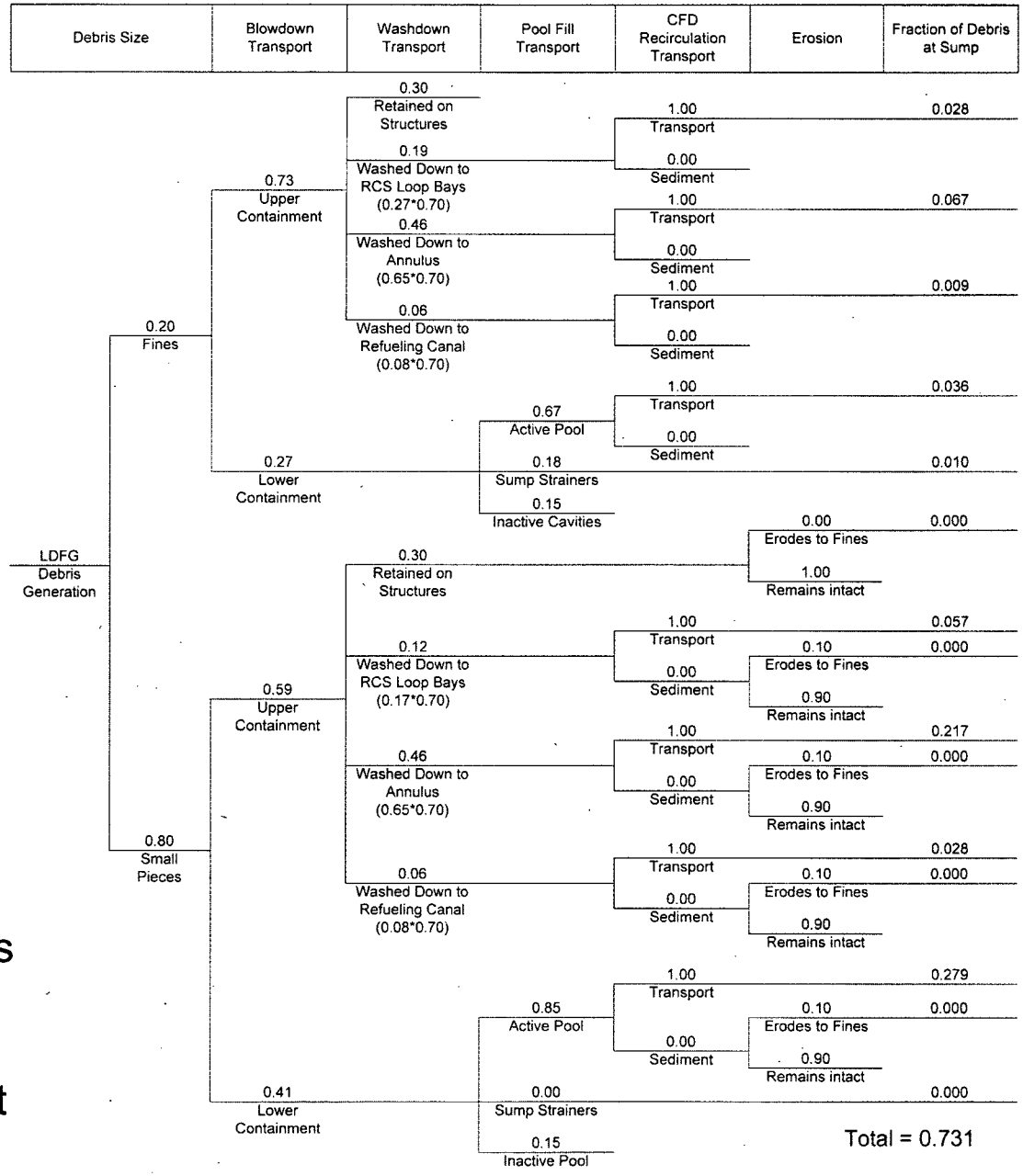


Figure 3.e.1.1-6 – Combined fiberglass logic trees with alternate BWROG washdown transport fractions

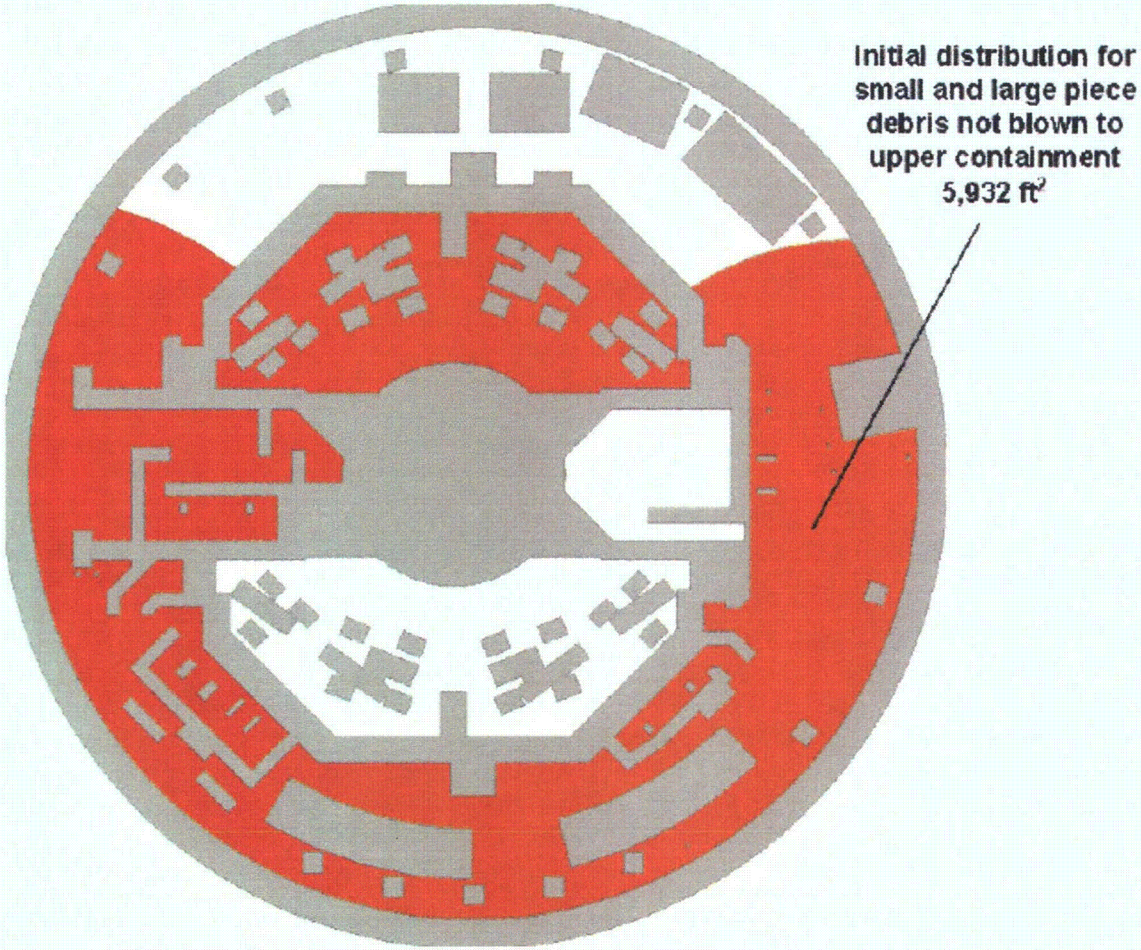


Figure 3.e.1.1-7 – Distribution of small and large piece debris not blown to upper containment

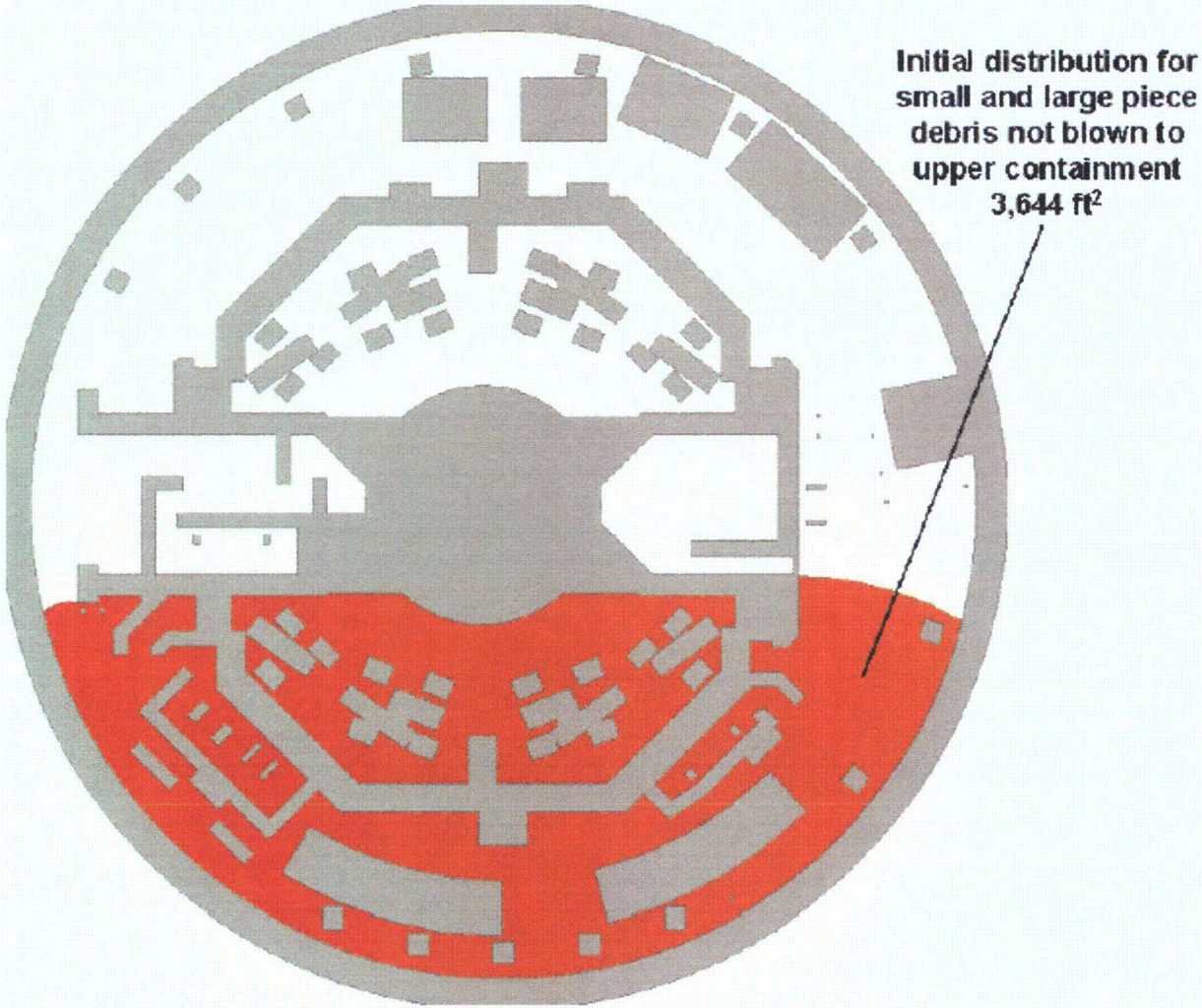


Figure 3.e.1.1-8 – Distribution of small and large piece debris not blown to upper containment

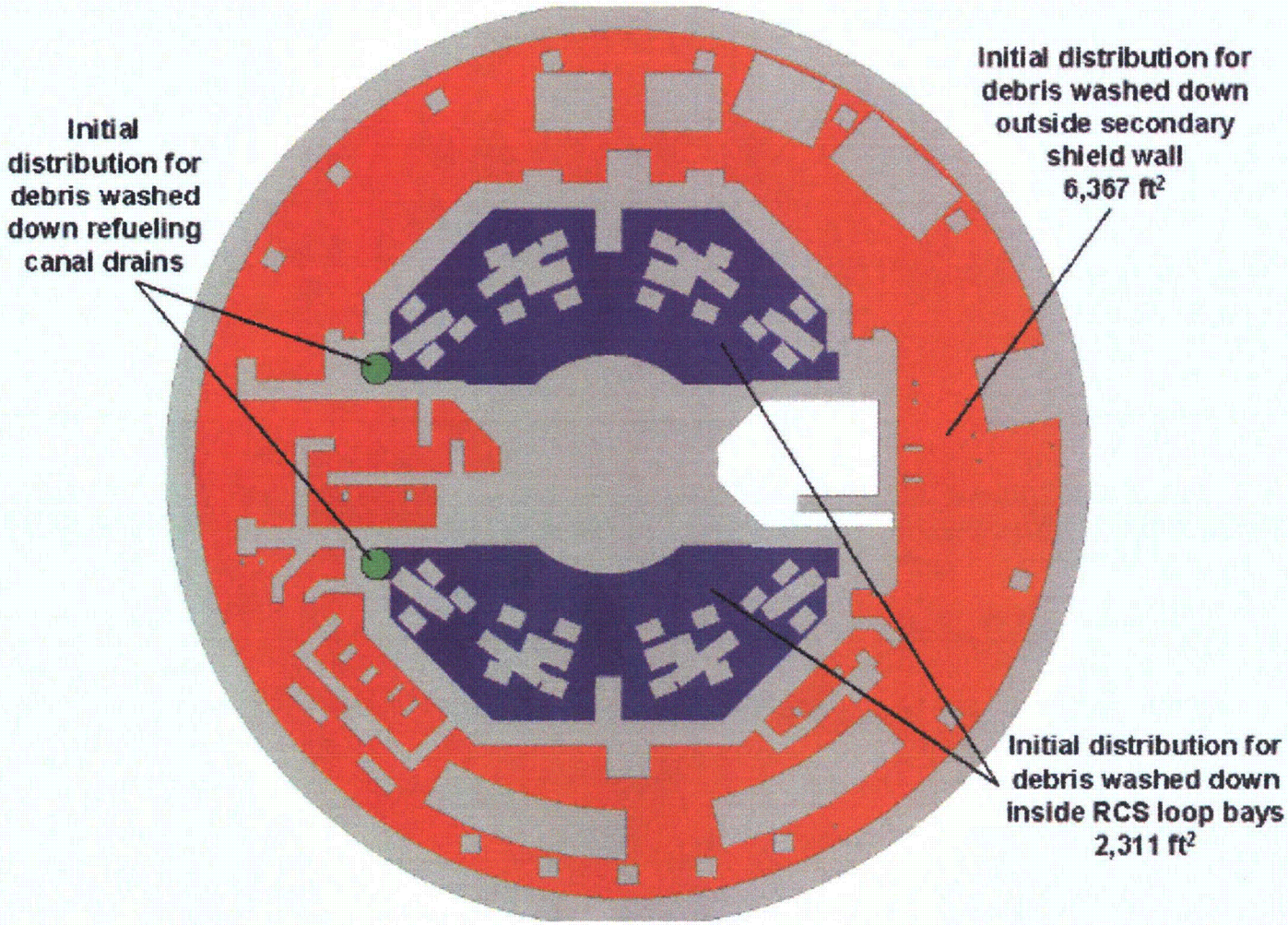


Figure 3.e.1.1-9 – Distribution of debris washed down from upper containment

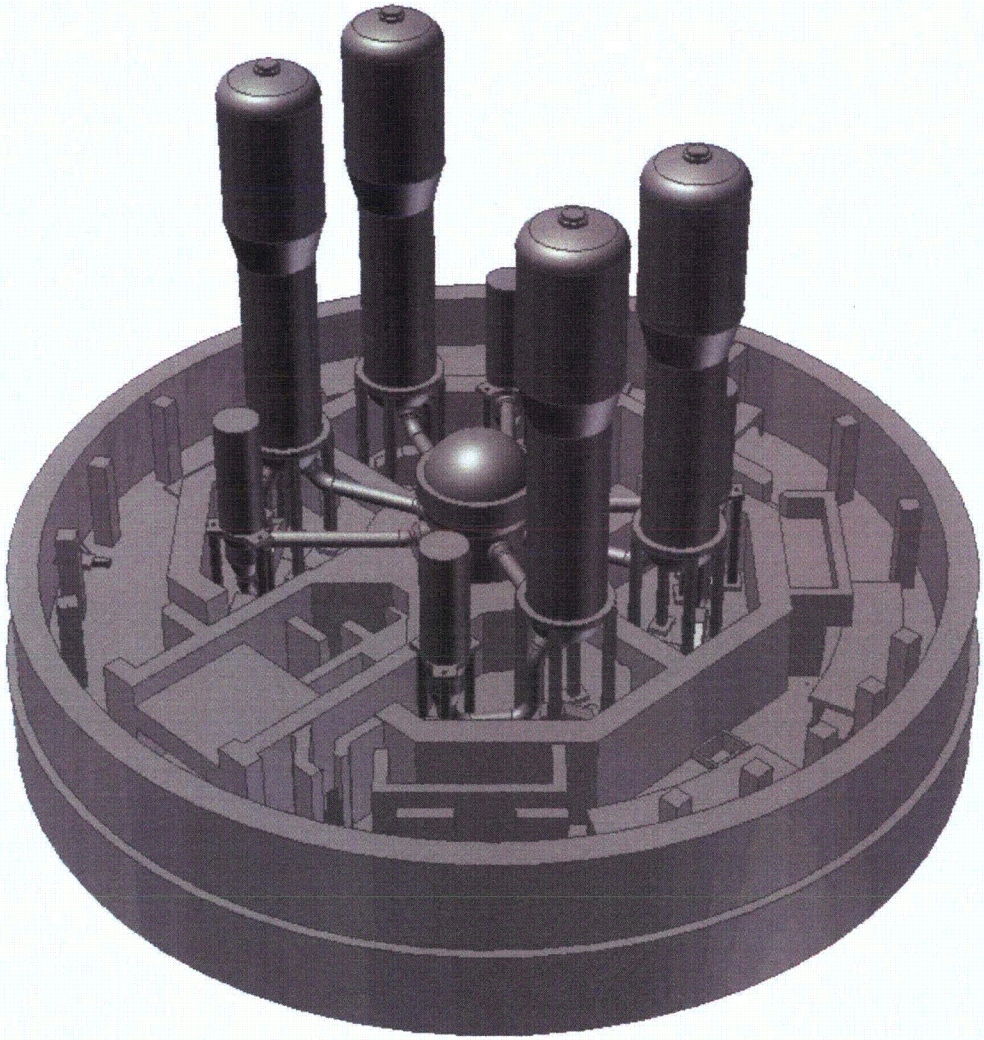


Figure 3.e.1.2-1 Northwest isometric view lower containment CAD model

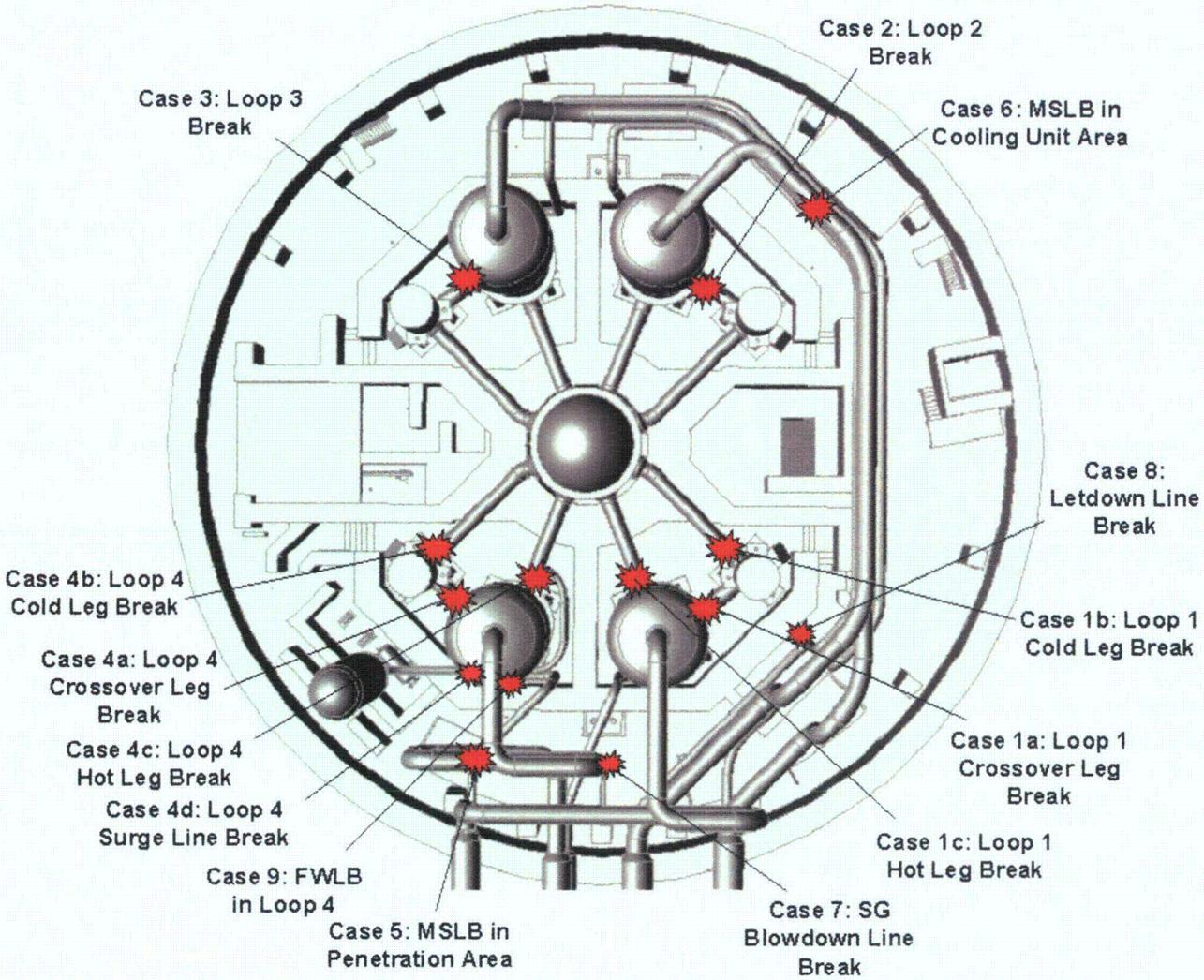


Figure 3.e.1.2-2 Postulated Break Locations

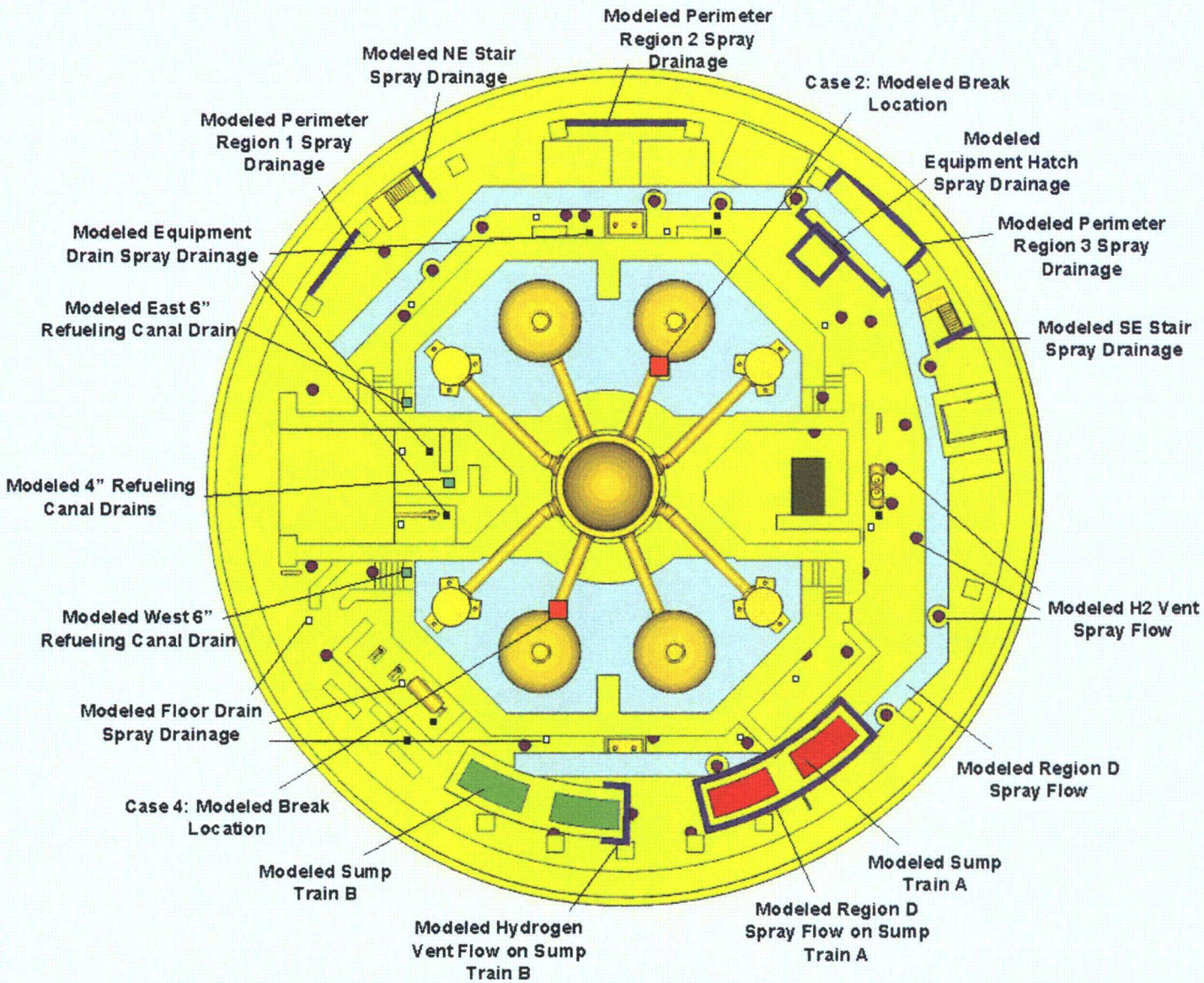


Figure 3.e.1.2-3 Diagram of significant features modeled

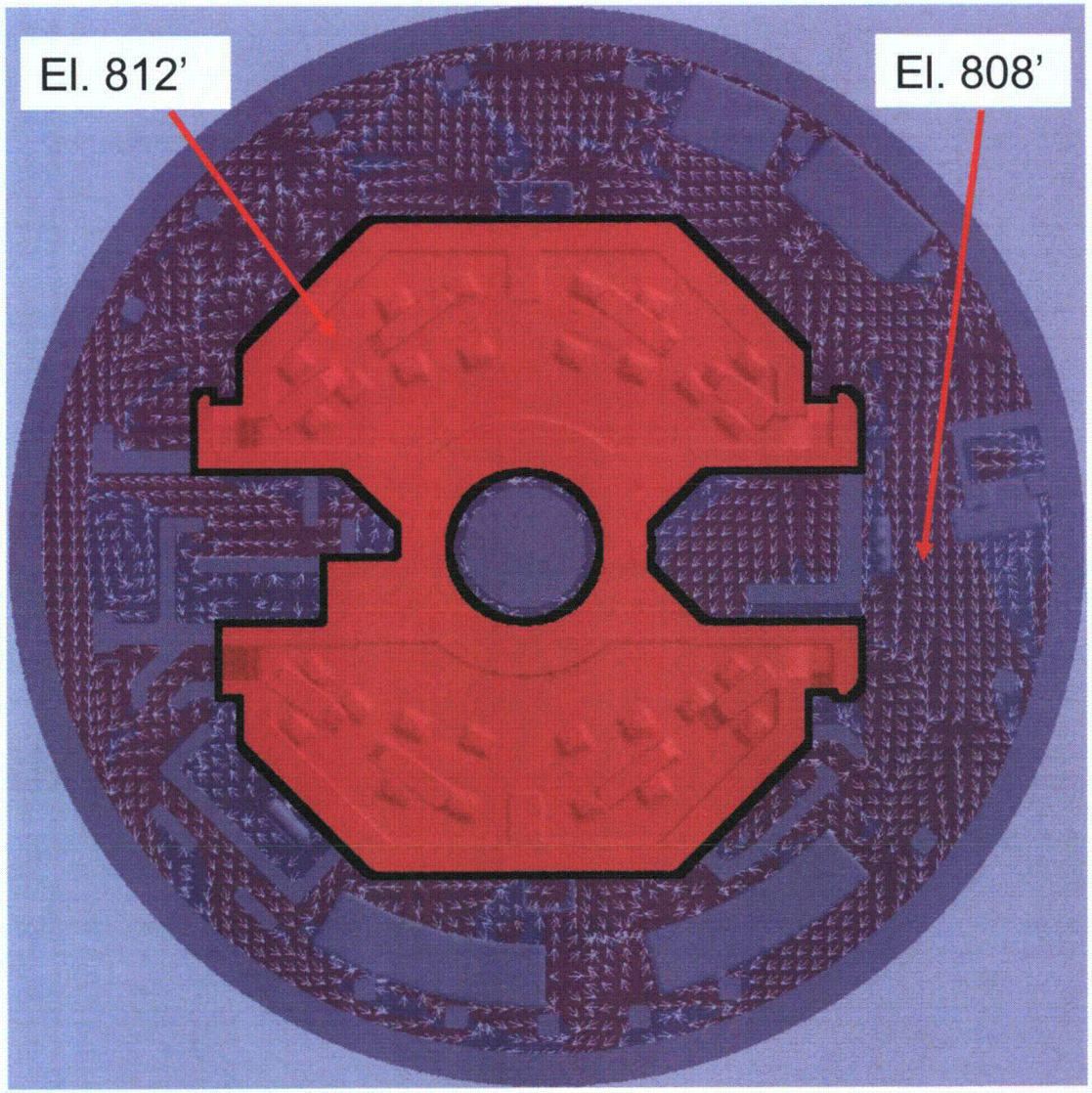


Figure 3.e.1.2-4 Illustration of distinct floor levels

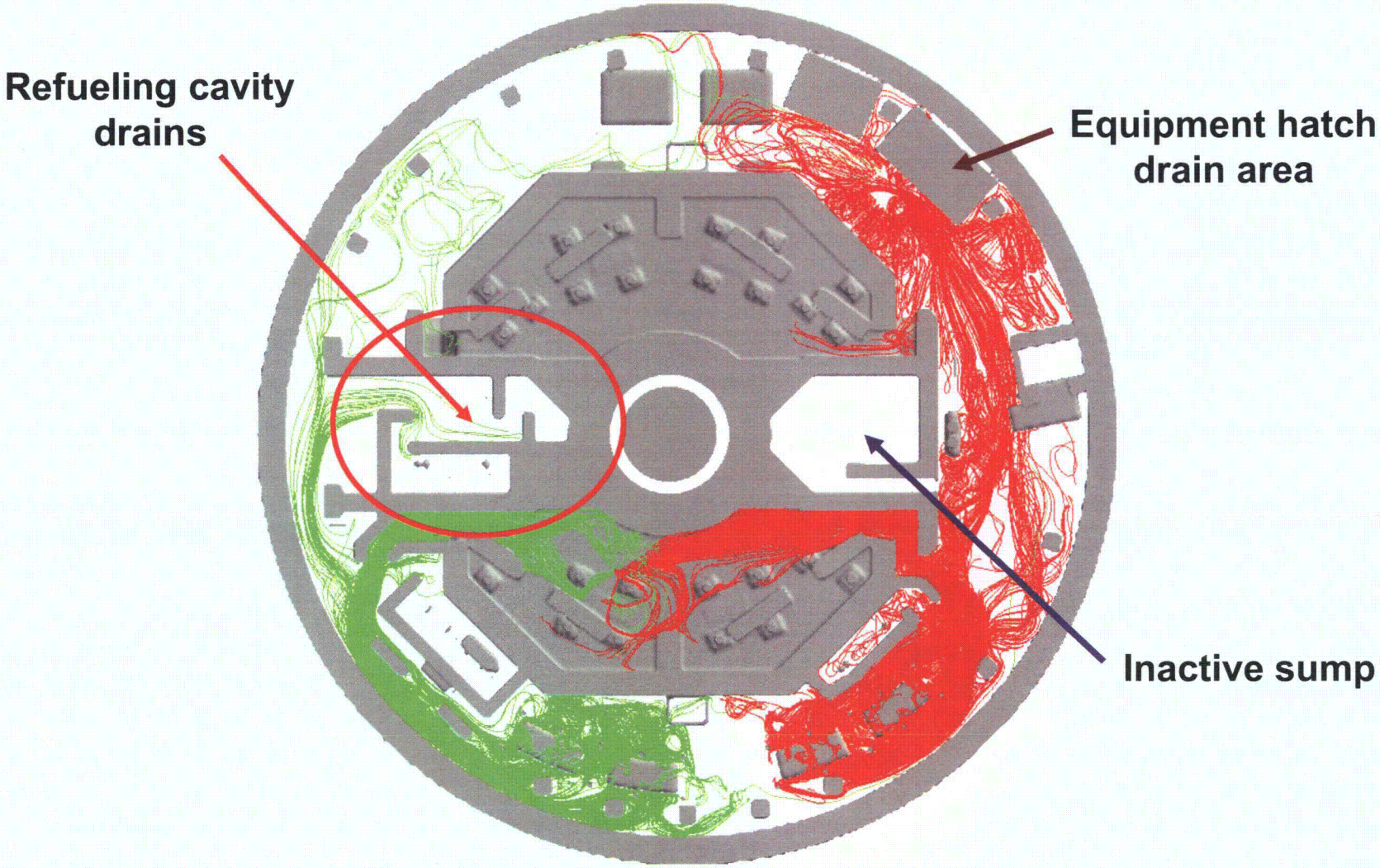


Figure 3.e.1.2-5 Streamlines showing water origination areas for each sump (Loop 4 LBLOCA, two trains)

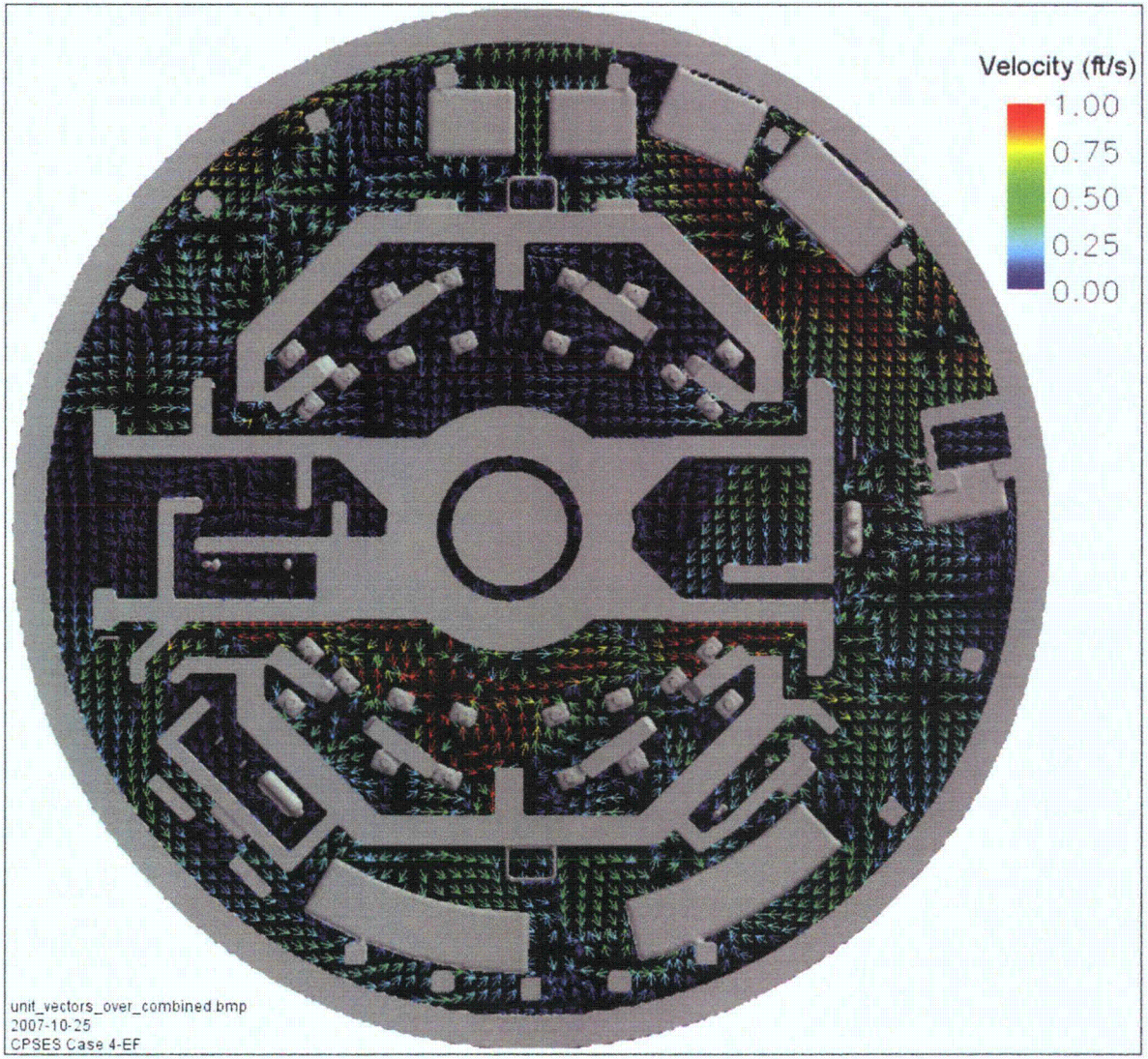


Figure 3.e.1.2-6 Vectors showing pool flow direction (Loop 4 LBLOCA Single Train Sump A)

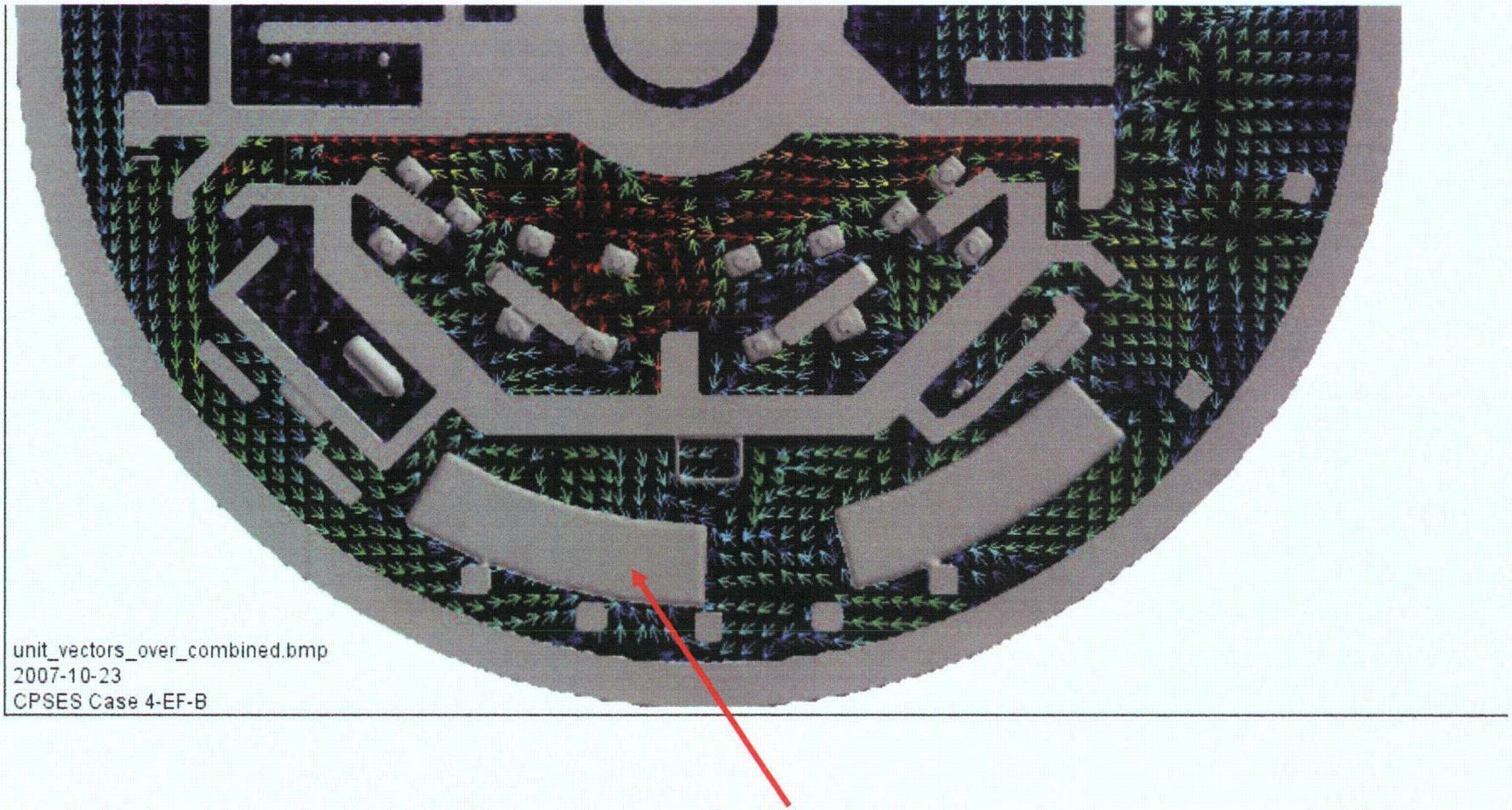


Figure 3.e.1.2-7 Loop 4 LBLOCA Single Train Sump B

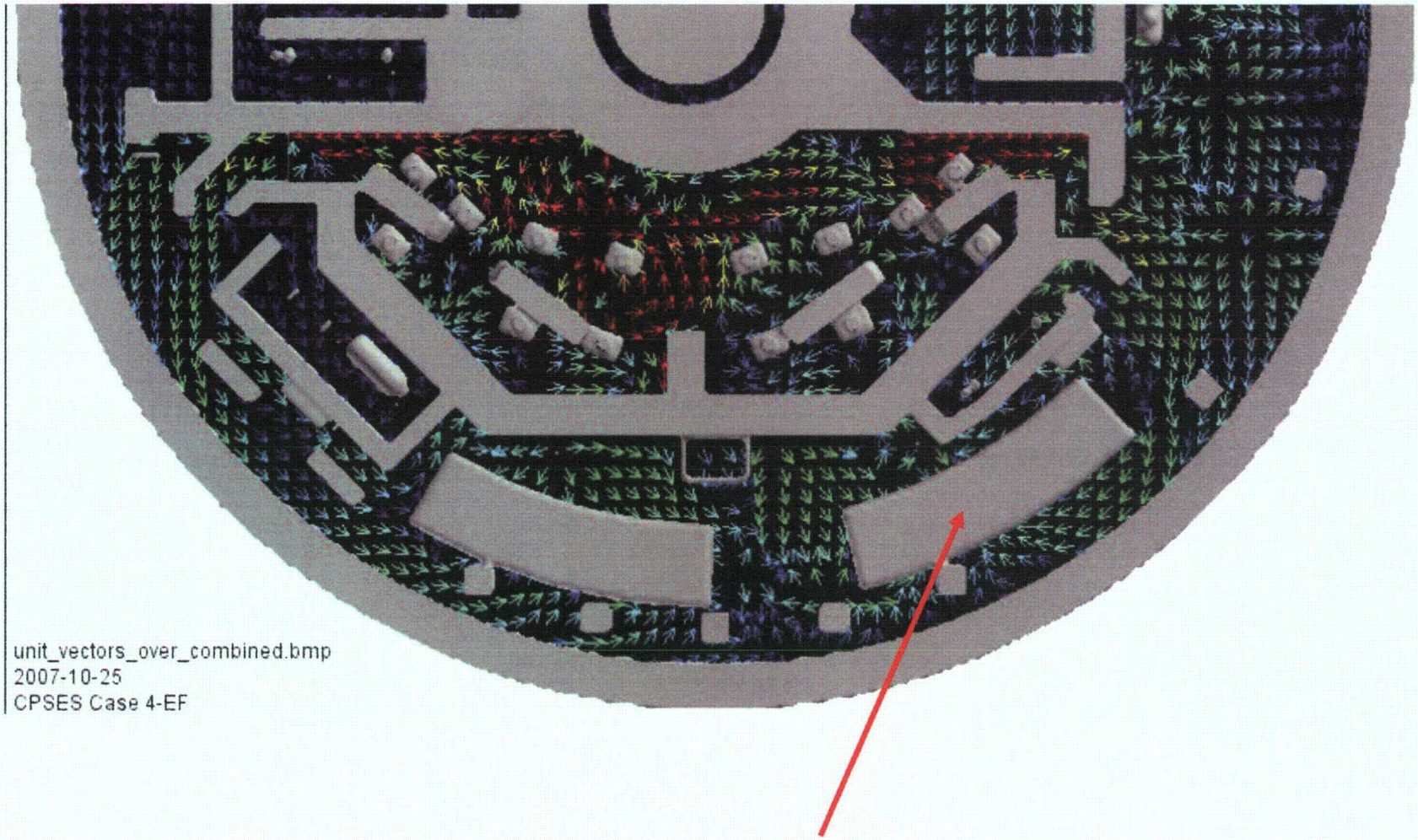


Figure 3.e.1.2-8 Loop 4 LBLOCA Single Train Sump A

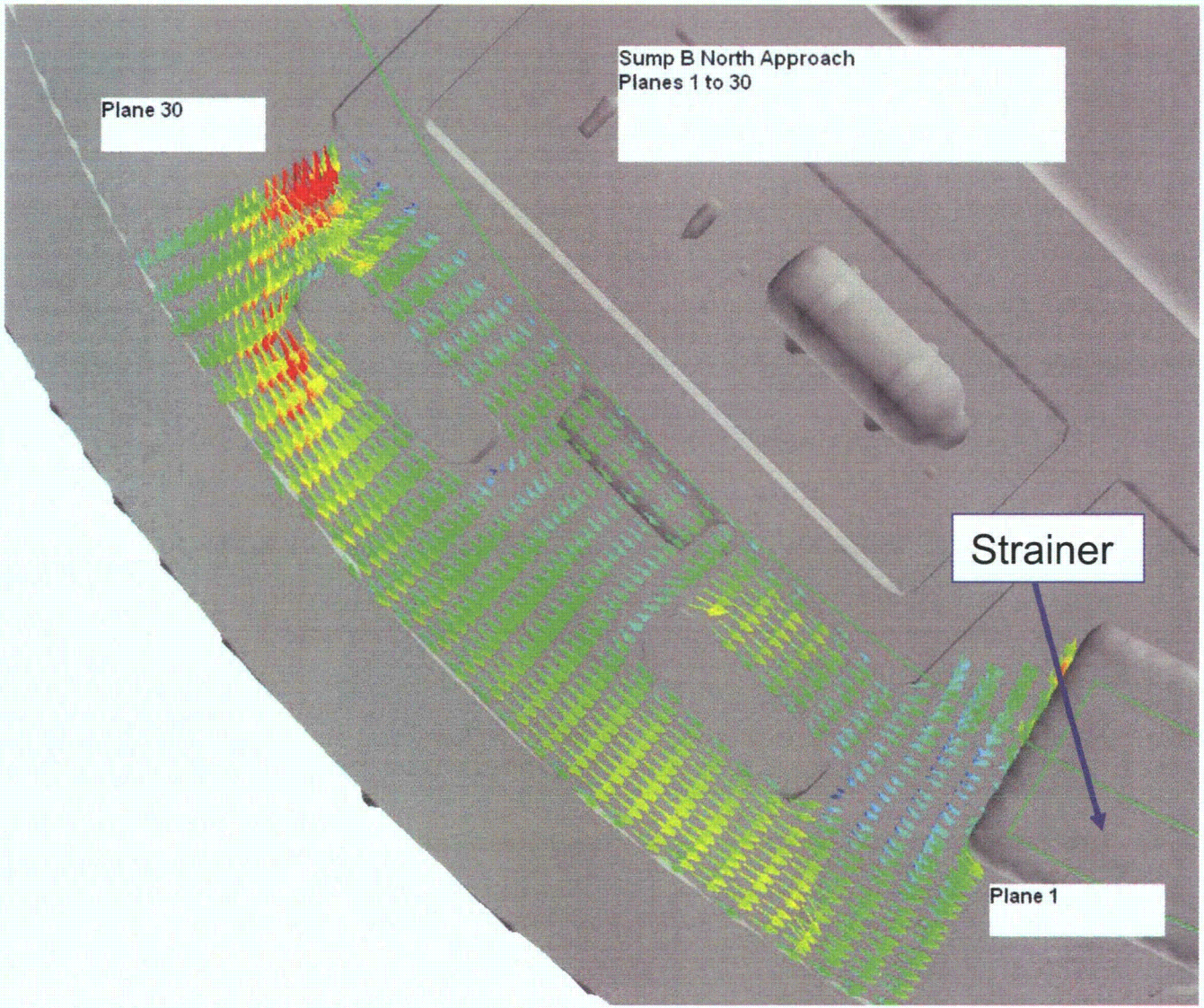


Figure 3.f-1 Cutting Planes for Test Flume Modeling

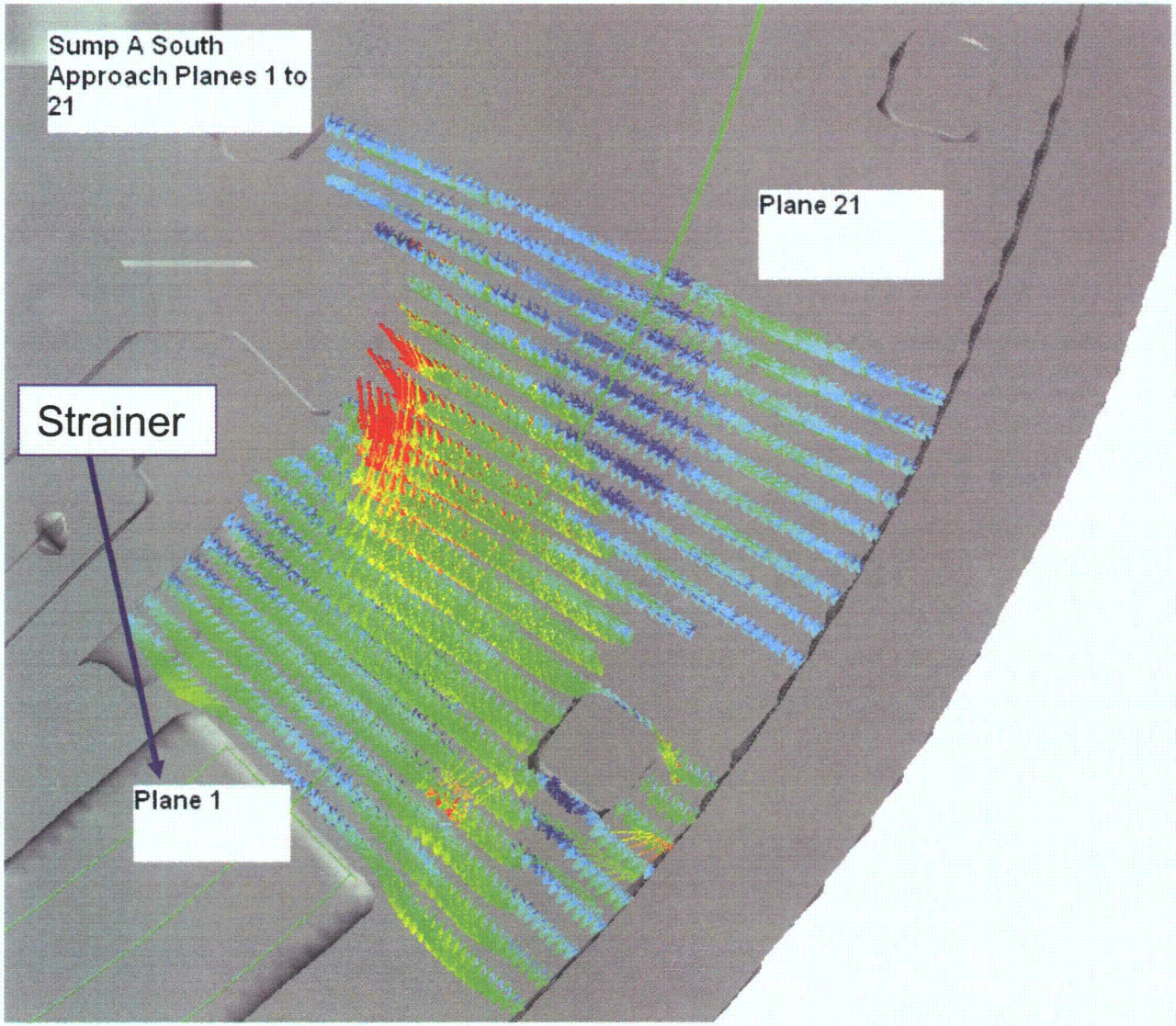


Figure 3.f-2 Cutting Planes for Test Flume Modeling

Figure 3.f-3 Prepared Large LDFG (Nukon) - Dry

Figure 3.f-4 Prepared Large LDFG (Nukon) - Wet

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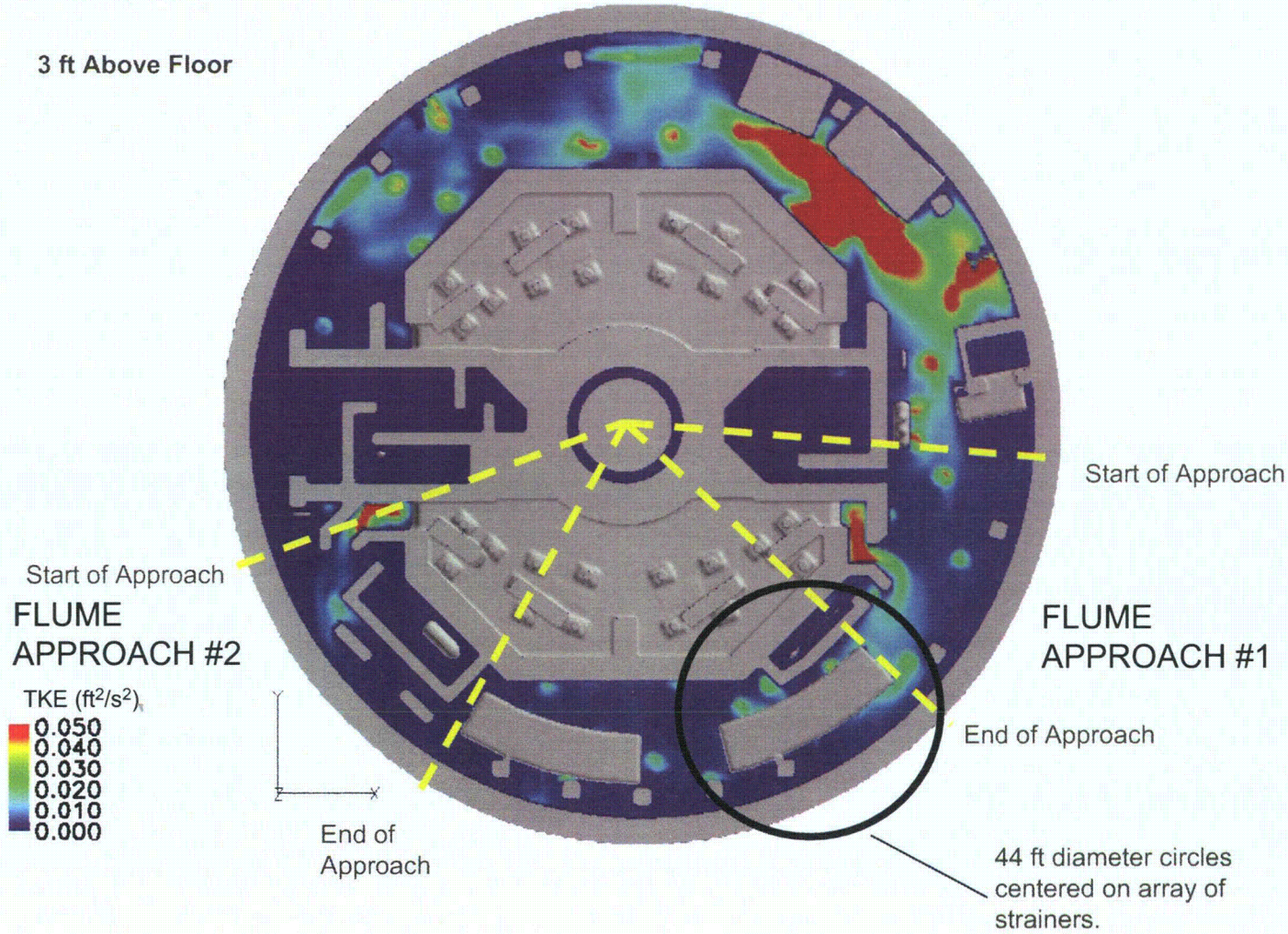
Recap

- Turbulence and flow are related
  - Literature treats suspension in terms of shear velocity
  - Literature would indicate that at most pieces smaller than 1"x1" could transport. All others cannot.
  - Experimental values for TKE required for suspension are much higher than analytical values.
- TKE comparison between flume and containment
  - Containment point sources of turbulence lead to higher levels of TKE in containment vs. flume
  - Containment TKE levels were reported on the flume approach, not the prototypical approach path.
  - Turbulent kinetic energy levels are low relative to what can reasonably expected to affect transport.
    - Random velocity fluctuations are small relative to mean.

Containment Turbulent Kinetic Energy
One Train Operation (A)



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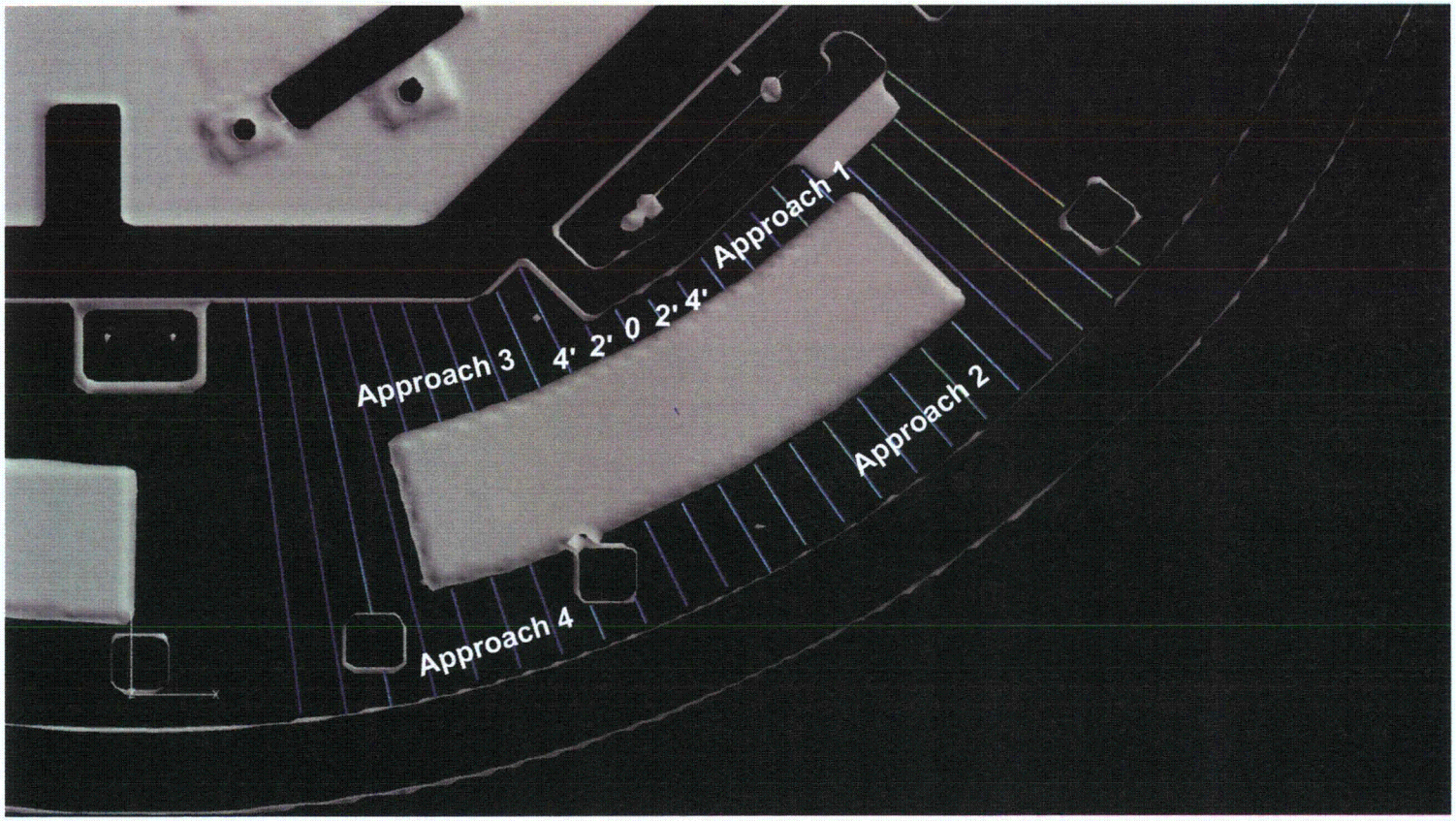
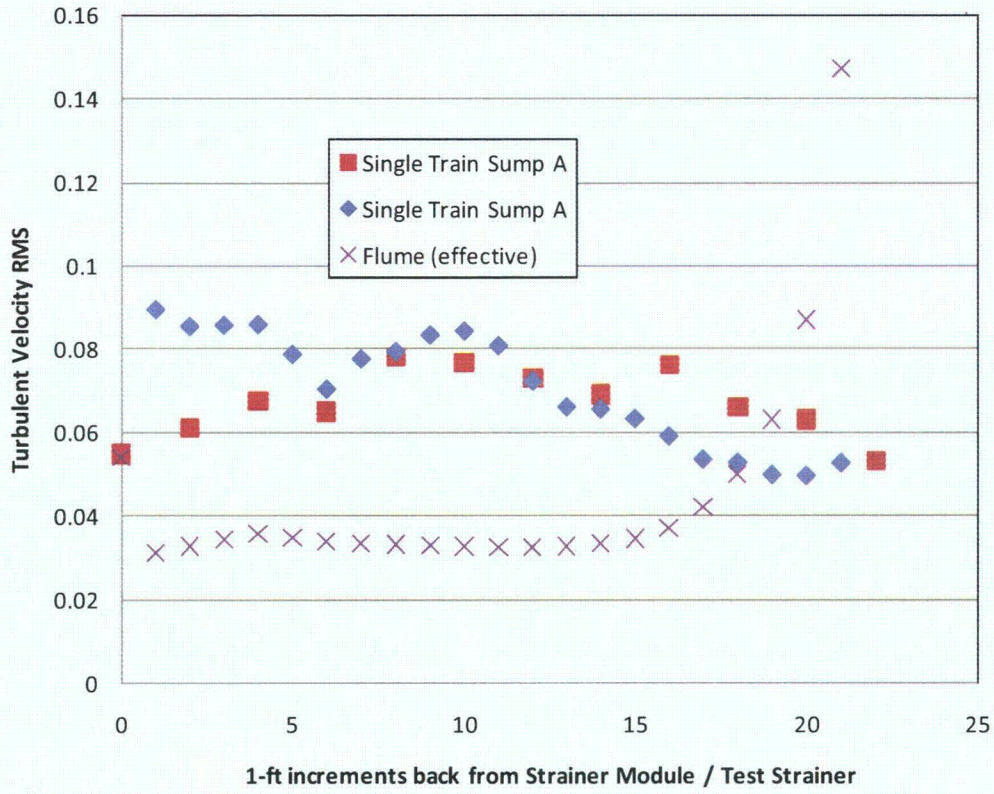
Prototypical single strainer approach

- Look at four approaches to central strainers



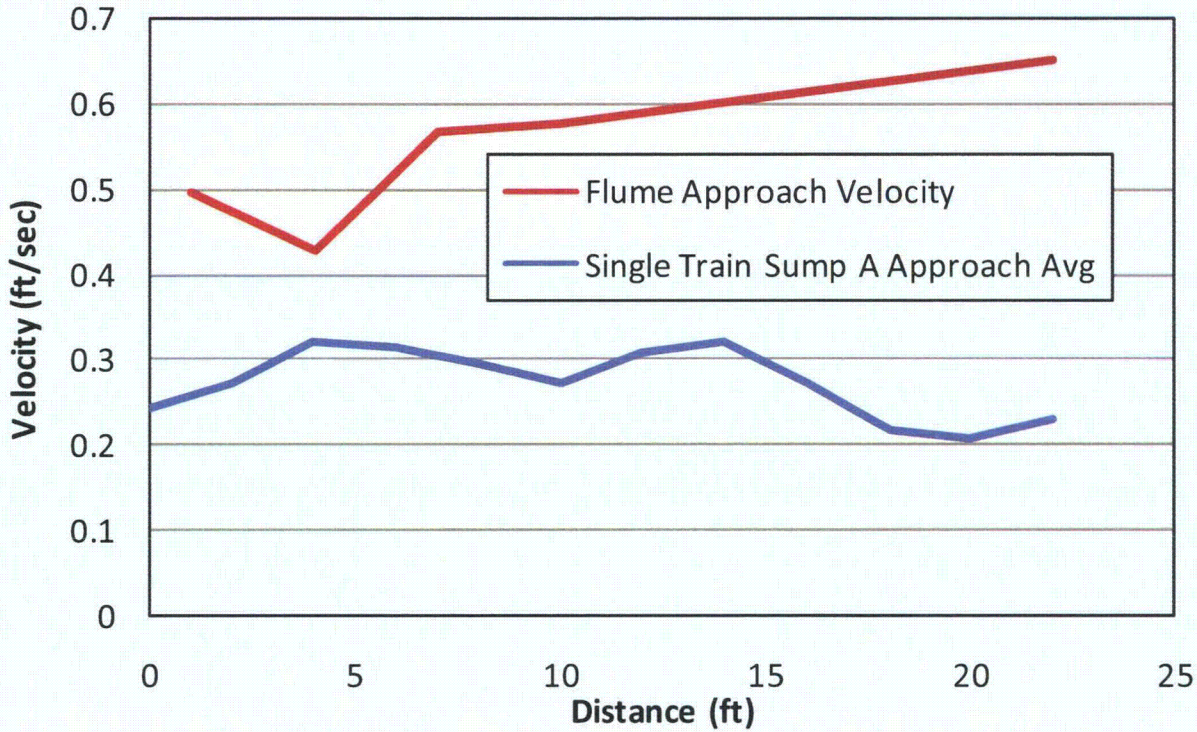
Turbulence Approach TKE

- Typical approach turbulence velocity is slightly lower



Typical Approach Velocity

- Flume approach is **VERY conservative** relative to containment



Conclusions

- Flume turbulence is lower
  - Importance is very questionable
  - Magnitudes of random velocity fluctuations are low relative to mean
- The key to transport is BULK VELOCITY
  - Flume velocity is **DOUBLE** relative to typical containment approach velocity for single train sump A operation.

General Overview

- Discussion of conservative representation of containment approach velocities in test flume
- Discussion of relevant physics of turbulence
  - Role of turbulence in debris suspension
    - NEI 04/07
    - Open Literature
- Overview of CFD predicted containment turbulence
- Overview of CFD predicted flume turbulence
- Discussion

RAI 10 & 11

- Are flume flow turbulence conditions prototypical of conditions in containment ?
- Are point sources of turbulence near modeled areas of containment accounted for in the flume ?

Containment Average Approach Velocity Representation in Test Flume

- At each 1 ft increment back from each strainer array along the water approach path to the strainers, calculate the weighted average of the velocity along a vertical plane:
  - The weighted average at each increment is weighted by twice the fastest velocity at the increment under consideration.
  - Low velocities in wake regions behind obstacles were ignored
  - Only velocity vectors pointing towards the strainer array were considered
  - Low velocities in the near wall regions were ignored

Physics of Turbulence
Turbulent vs. Laminar Flow

- Turbulent (Re > 2000) vs. Laminar Flow (Re < 2000)
  - $Re = UR_h/\nu > 2000$ for open channel flow [1]
    - U = Characteristic Velocity
    - R_h = Characteristic Length Scale = Hydraulic Radius
    - ν = Kinematic Viscosity
  - Calculation for Containment and Flume

	Flume		Containment	
	Min	Max	Min	Max
Velocity (ft/sec)	0.4	0.5	0.4	0.5
Width (ft)	0.3	0.45	-	-
Depth (ft)	4.17		4.17	
Kinematic viscosity (ft^2/sec)	8E-06		3E-06	
Hydraulic Radius (ft)	0.14	0.21	4.17	
Re	7240	13343	556000	695000

  - Conclusion: Flow in Flume is Turbulent

[1] "Flow through open channels", Raju, K.G.R., McGraw-Hill, 1981.

Physics of Turbulence
"Magnitude" of Turbulence

- Turbulence Level is a function of Shear Velocity [2]
  - By Definition [2]: $u^* = \sqrt{\frac{f \cdot U^2}{8}}$ f – Darcy-Weisbach friction factor; u*- shear velocity
  - Magnitude of Turbulent Velocity Fluctuation:
    - u' = u* (2.3 exp (-y/h)) for y/h < 0.1 [3]
    - u' = u* (1.27 exp (-y/h)) for y/h => 0.1 [3]

      Where:

      u' = Turbulent Fluctuating Velocity
      u* = Shear velocity
      y = Vertical Length Scale
      h = Depth of Flow
- Note:
  - $f_{containment} \sim f_{flume}$
  - $y_{containment} = y_{flume}$ and $h_{containment} = h_{flume}$
- Expected flow turbulence levels in the flume due to flowing water are of the same order as containment

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[2] The Hydraulics of Open Channel Flow, Chanson, H., Arnold, 1999.

[3] Nezu, I and Azuma, R., 'Turbulence Characteristics and Interaction between Particles and Fluid in Particle-Laden Open Channel Flows", Journal of Hydraulic Engineering, October 2004.

Role of Turbulence in Suspension

- Turbulence studies have shown that the fluid shear velocity is directly related to turbulence level [3]
- Onset of debris suspension is expected to occur when the magnitude of the turbulent velocity fluctuation is greater by some margin than the settling velocity of the debris as defined by the following expression:

$$\frac{u^*}{w_o} > \text{critical value}$$

w_o – settling velocity

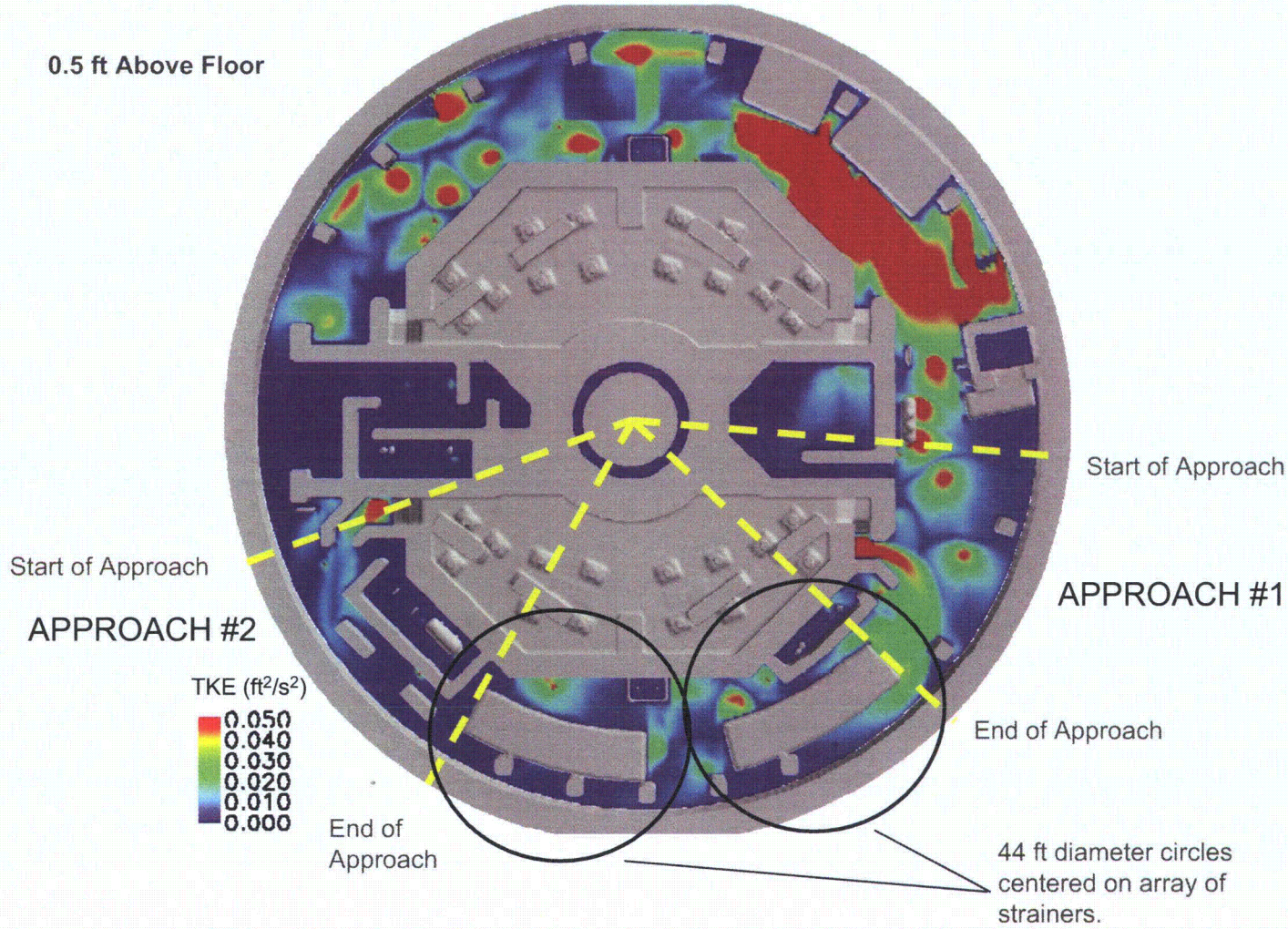
  - Open literature brackets the range of critical values: 0.2 to 2.0 [2]
  - Minimum Shear velocity, $u^*_{(\text{Flume and Containment})} = 0.031$ ft/s
  - Range of settling velocity susceptible to suspension:
    - Material with settling velocity < 0.15 ft/sec (c.v. = 0.2)
    - Material with settling velocity < 0.06 ft/sec (c.v. = 2)

Role of Turbulence in Suspension

- Table 4-2, NEI 04/07
  - Only loose fibers easily suspended by turbulence (w_o<0.15 ft/s)
  - Only ¼" x ¼" clump turbulence requirements verified experimentally (Analytical TKE levels questionable as indicated in SER)
  - Experimental value tends much higher than analytical value

Debris Category/Type	Size	Density (lbm/ft^3)	Terminal Settling Velocity (ft/sec)	Minimum TKE Required to Suspend (ft^2/sec^2)
A. Fibrous Insulation				
1. Fiberglass – Generic				
2. Fiberglass – Nukon	a. 6"	a. 2.4	a. 0.41	a. 0.084
	b. 4"	b. 2.4	b. 0.40	b. 0.080
	c. 1"	c. 2.4	c. 0.15	c. 0.011
	d. 1/4"x 1/4" clumps	d. 2.4	d. 0.175	d. 0.14
	e. loose fibers	e. 175	e. 0.008	e. 3E-05

Containment Turbulent Kinetic Energy
Two Train Operation



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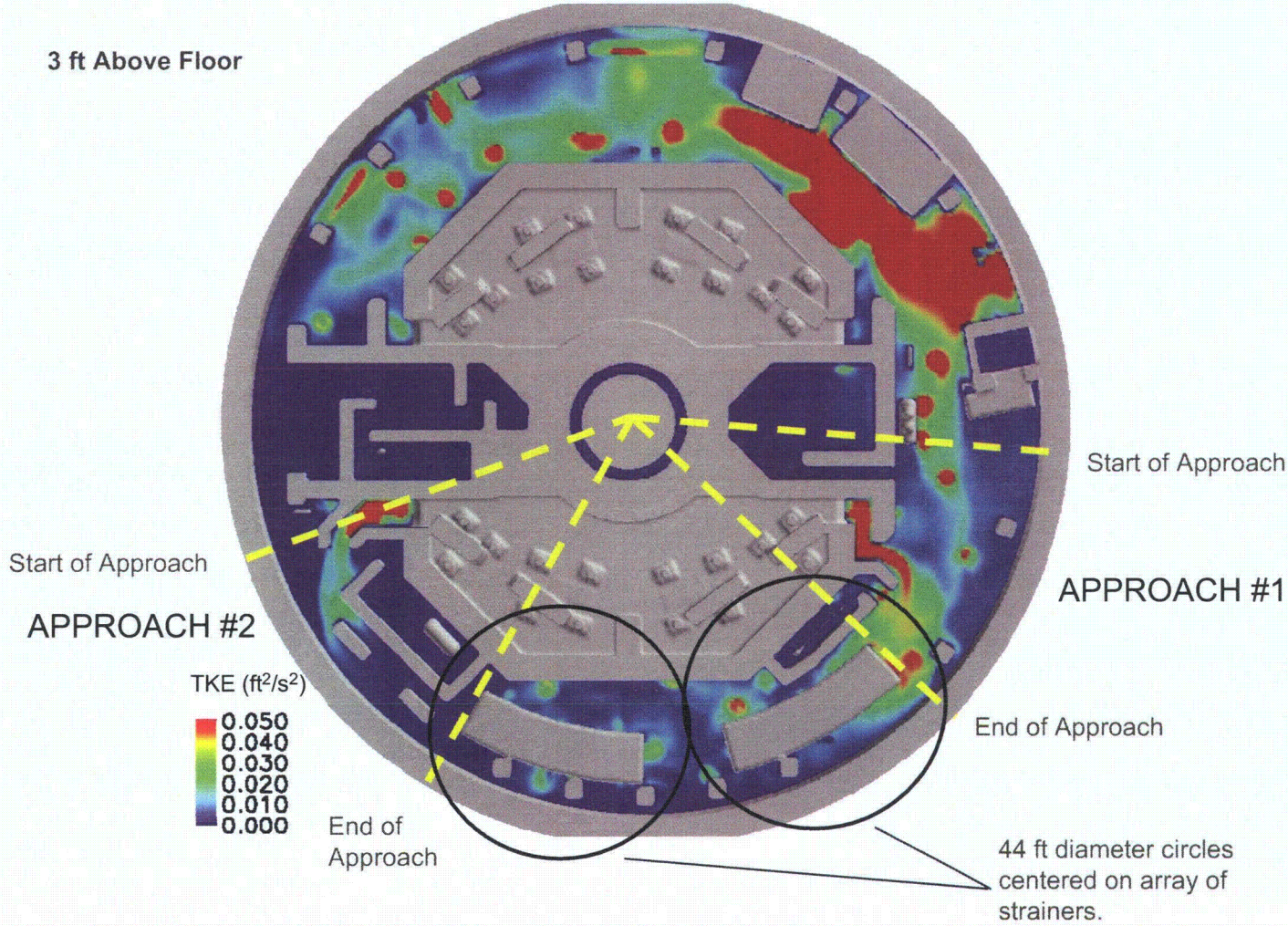
Containment Turbulent Kinetic Energy
Two Train Operation



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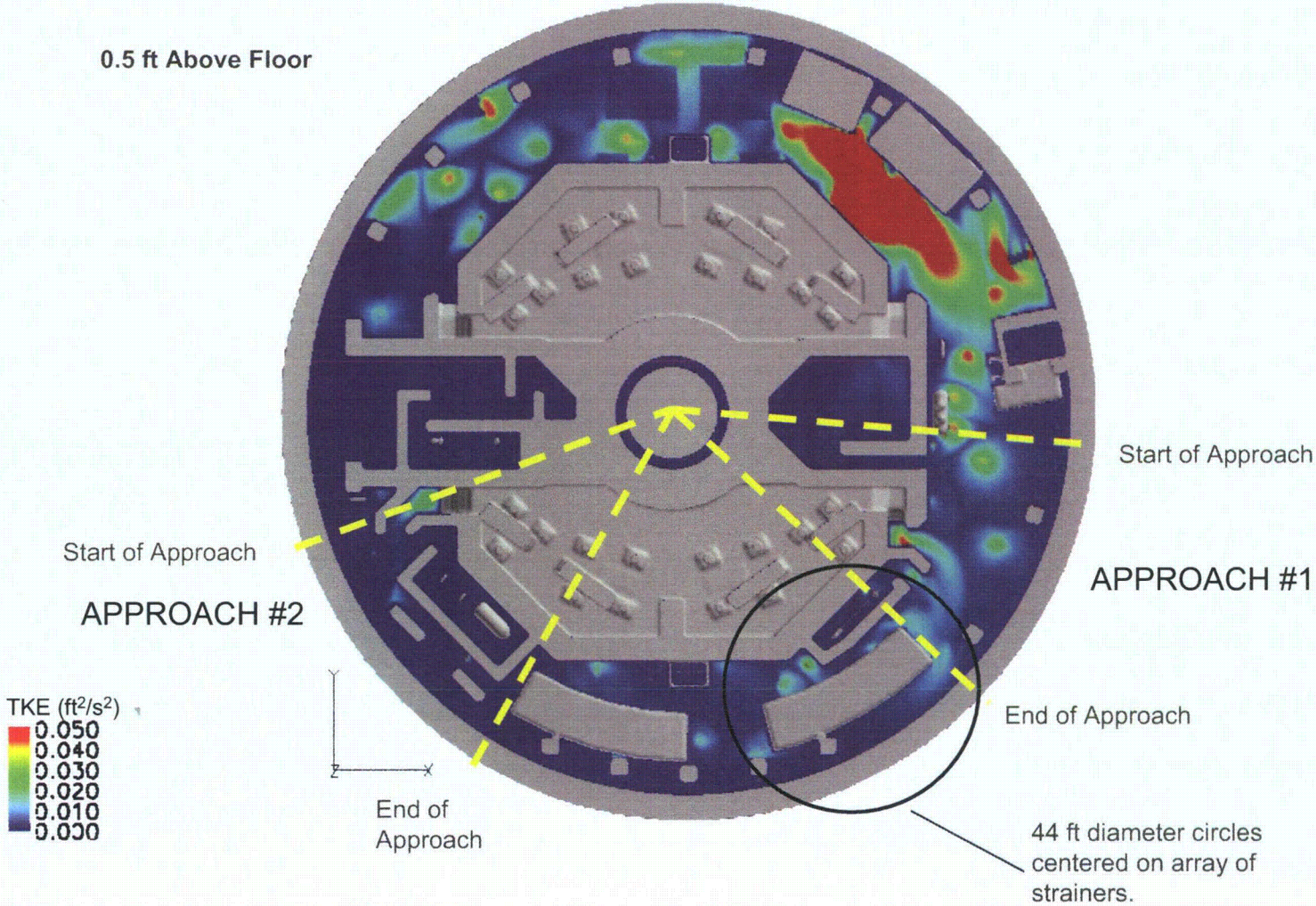
Containment Turbulent Kinetic Energy
One Train Operation (A)



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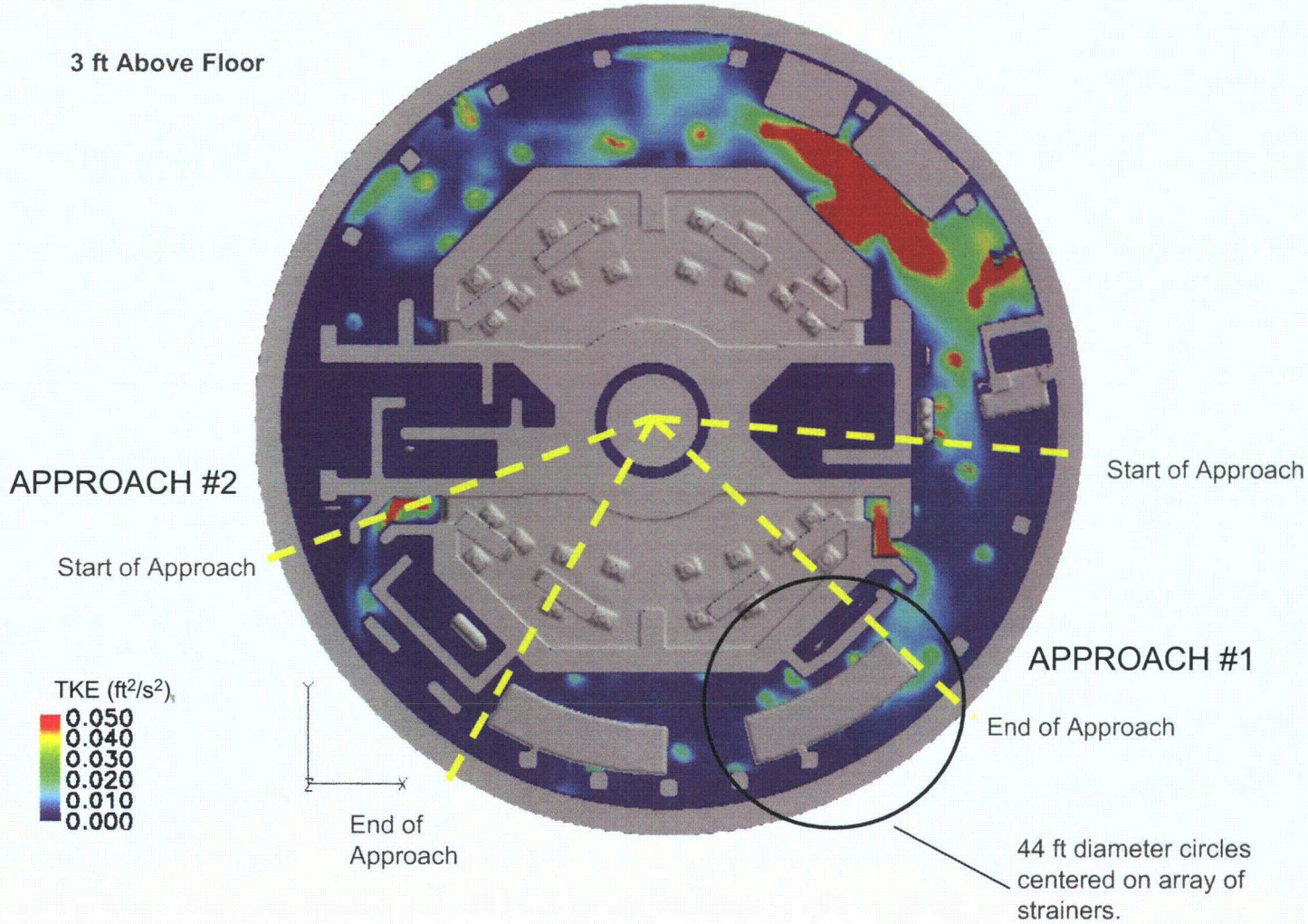
Containment Turbulent Kinetic Energy
One Train Operation (A)



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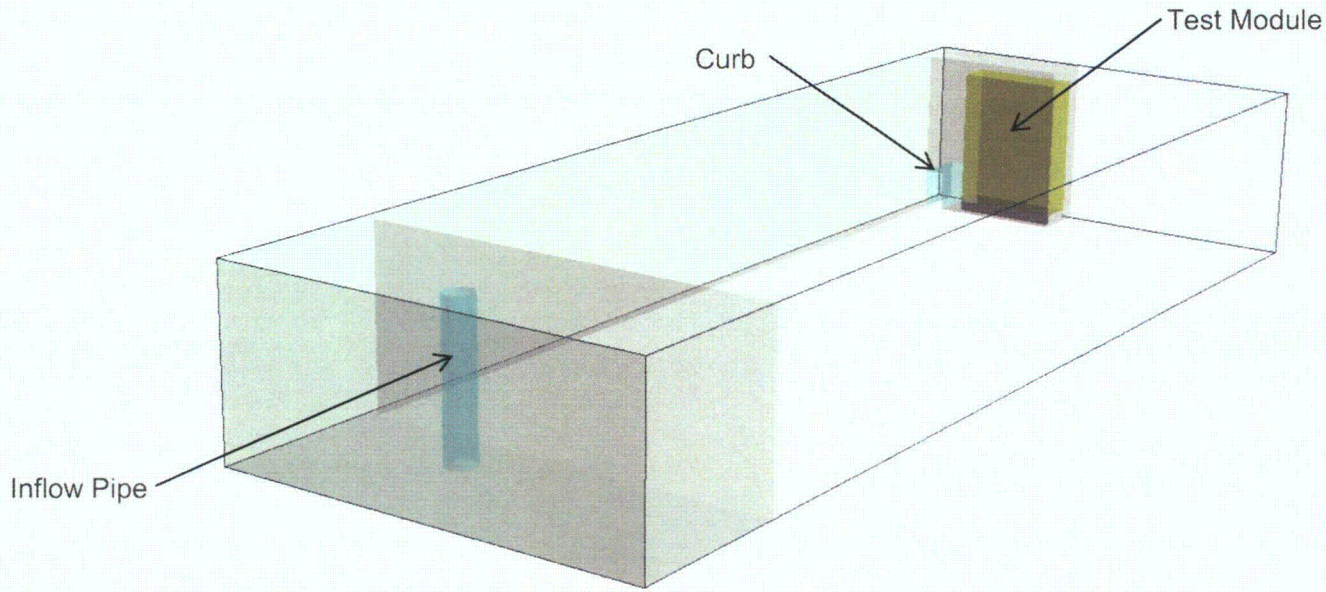
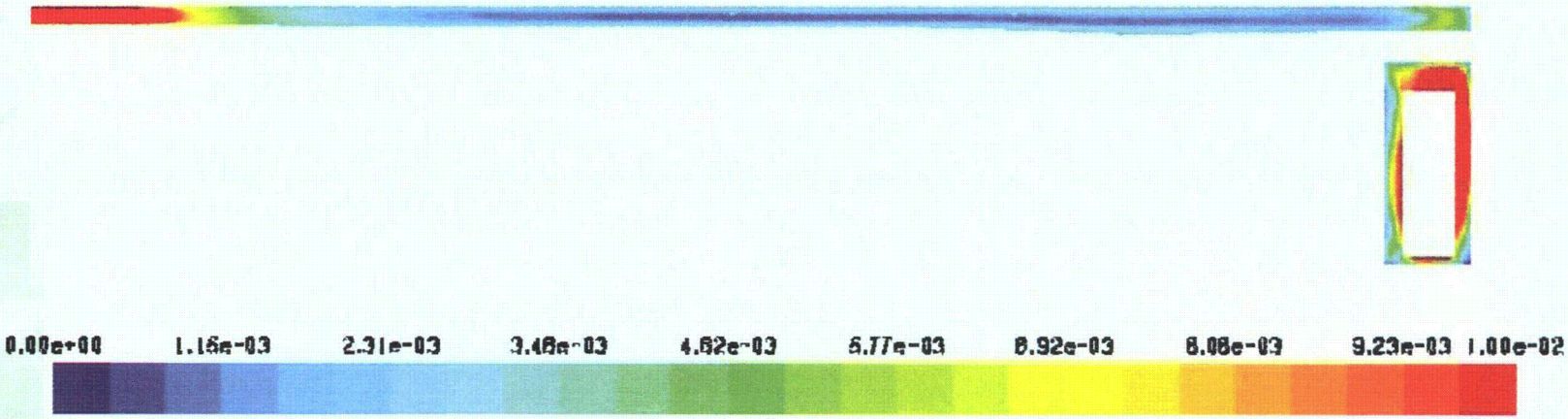
Test Flume Turbulent Kinetic Energy
CFD Geometry

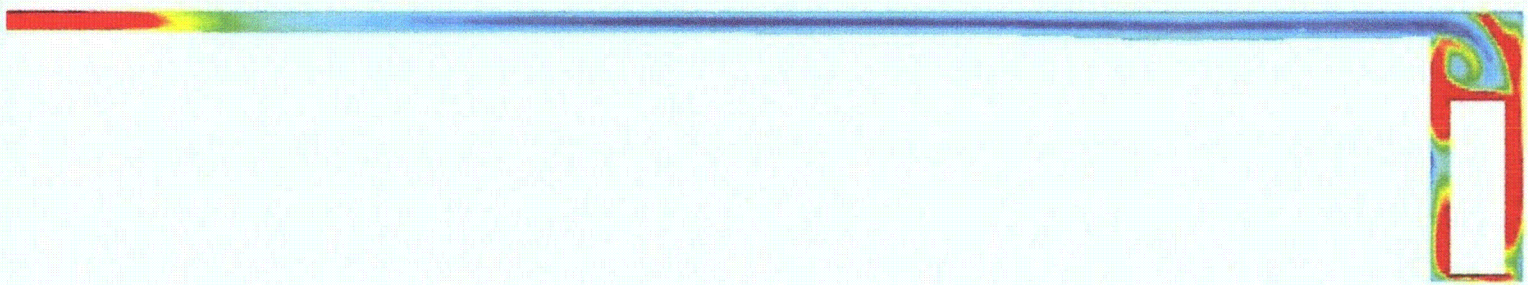


Test Flume Turbulent Kinetic Energy

- 0.5 ft above floor



- 3 ft above floor



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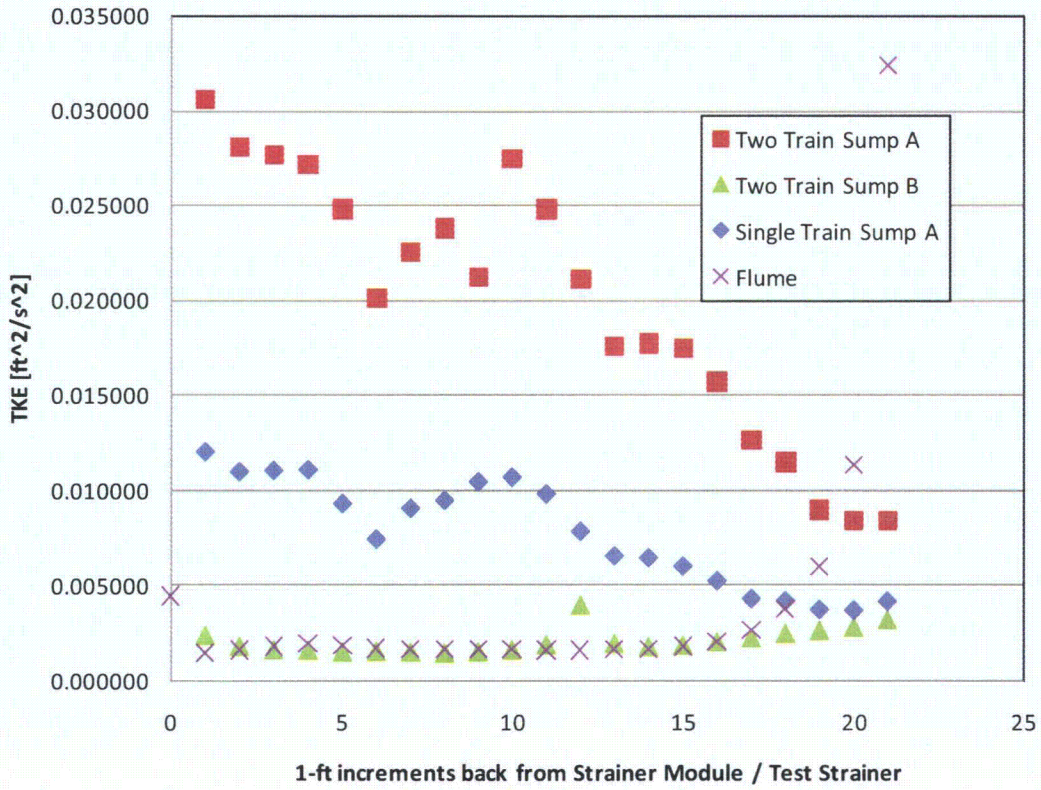
Turbulent Kinetic Energy Profiles

- Area averaged quantities for planes back from sump / strainer



Summary of Comparison

- Flume turbulence levels on par with Approach #2 to strainers in containment for both one and two train operation.
- For one train operation, turbulence level in the flume is on the order of that in the plant over most of Approach #1.
- The flume turbulence level near the test strainer is similar to the higher turbulence in the field at the upstream end of the array.
- For areas where flume turbulence is lower than containment:
  - Greatest part of turbulent kinetic energy is <u>below</u> estimated required level for suspension of 1" smalls based on settling velocities
  - Fines are suspended by both flume and containment turbulence levels
  - Debris > 4" is not able to be suspended by either containment or flume turbulence levels

Summary of Comparison (cont'd)

- Settling velocity is proportional to the inverse of viscosity
  - Between flume (120F) and containment (~200F) viscosity is half
- Effective turbulence level in the flume is double due to lower settling velocity in flume

RAI Response Summary

- Flume flow conditions are turbulent and are representative of flow generated turbulence.
- Turbulence levels observed are in general not sufficient to keep smalls above 1" suspended in containment or flume.
- Near strainer turbulence levels are higher in the flume compared to containment calculated values.
- Point sources of turbulence from jetting located further away from the strainers are not modeled in the flume. However, blocking of debris by the flow structures existing in this area is also not considered.
- Point sources of turbulence are generally located outside the mean radius of travel modeled in the flume.