Simplified Equation for Gas Transport To Pumps

NEI Workshop
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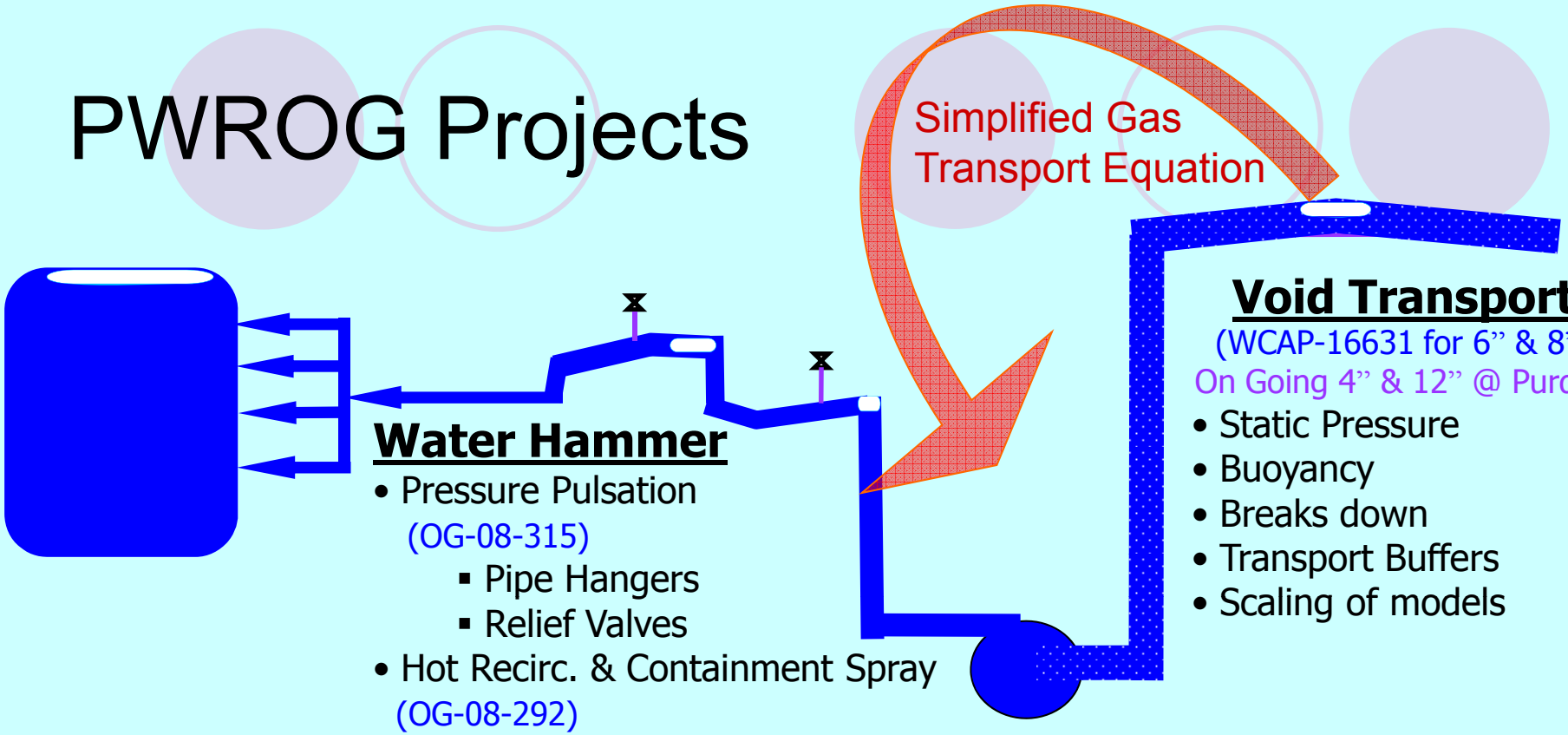
What Factors Could Result In Gas Generation ?

- Temperature
- Pressure

PWROG Projects



Water Hammer

- Pressure Pulsation
  (OG-08-315)
  - Pipe Hangers
  - Relief Valves
- Hot Recirc. & Containment Spray
  (OG-08-292)

Void Transport

(WCAP-16631 for 6" & 8")
On Going 4" & 12" @ Purdue

- Static Pressure
- Buoyancy
- Breaks down
- Transport Buffers
- Scaling of models

Non-Condensable Gas into the Reactor Vessel

(OG-08-293)

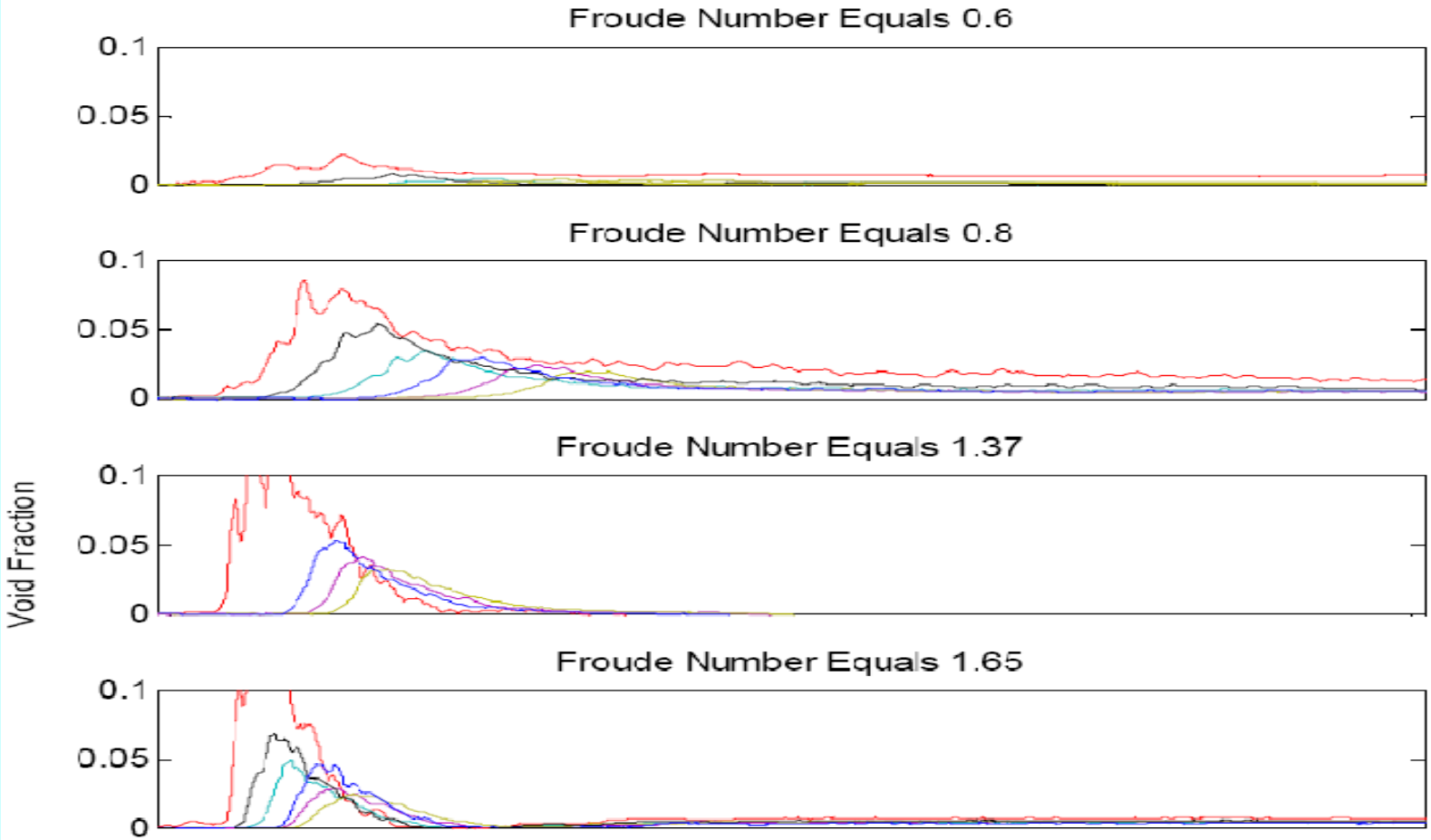
- ECCS Delay
- LOCA & Non-LOCA Qualitative Evaluation

Pump Interim Gas Ingestion Tolerance Criteria (V-EC-1866)

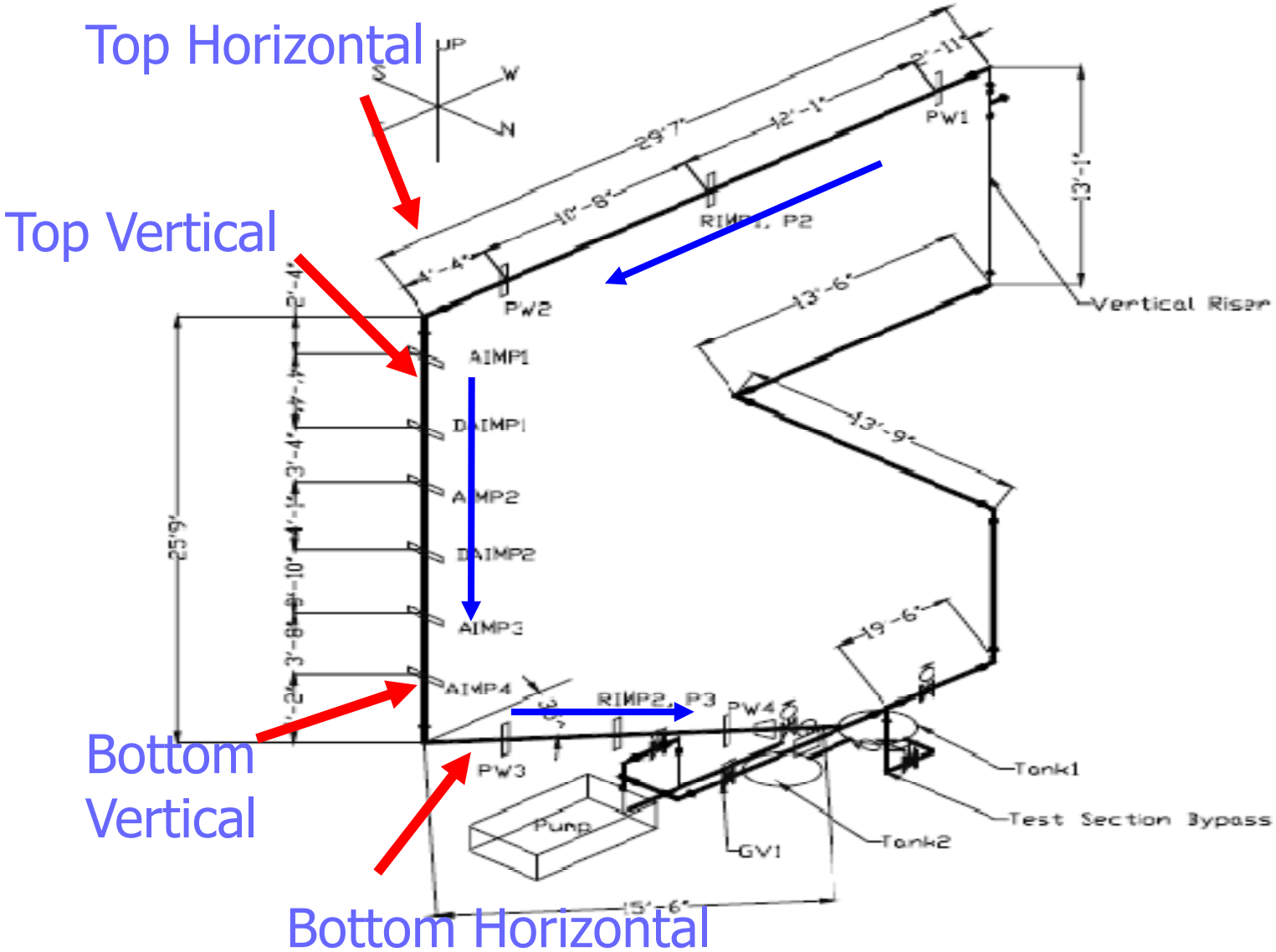
- Steady State & Transient Void Limits
- Types of Pumps
- Peak / Average Void Fraction
- Momentary TDH Degradation
- NPSHR vs. NPSHA

Gas Transport vs. Flow Rate

Observation 1: Higher flow results in higher void fraction (over a shorter duration) being transported



Test Loop at Purdue: Video Locations



Gas Transport vs. Flow Rate

Observation 2: Larger initial void volume results in larger void Fraction being transported

Identify Critical Parameters

- Observations:
  - Higher flow ➔ Higher Void
  - Larger initial void volume ➔ Higher Void
- Minimizing Void Transport to The Pump
  - Identify the maximum flow rate
  - Limit the allowable initial void

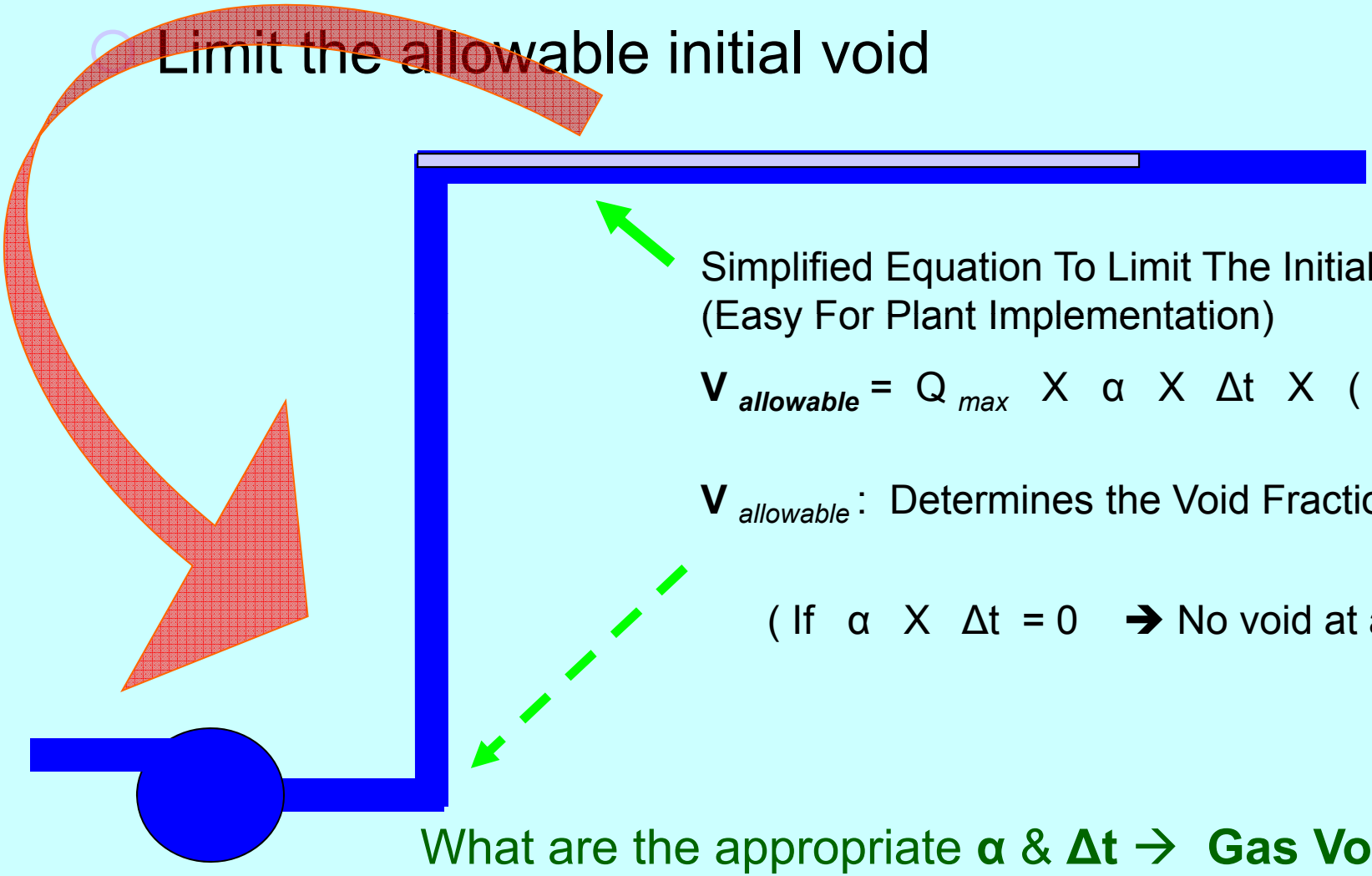
Simplified Equation vs. APC Criteria

	$\% \frac{Q}{Q_{BEP}}$	BWR Typical Pumps	PWR Typical Pumps		
			Single Stage (WDF)	Multi-Stage Stiff Shaft (CA)	Multi-Stage Flexible Shaft (RLIJ, JHF)
Steady State Operation > 20 seconds	40%-120%	2%	2%	2%	2%
Steady State Operation > 20 seconds (see Note)	< 40% or > 120%	1%	1%	1%	1%
Transient Operation ≤ 5 seconds	70%-120%	10%			10%
Transient Operation ≤ 5 seconds (see Note)	< 70% or > 120%	5%			5%
Transient Operation ≤ 20 seconds	70%-120%		5%	20%	
Transient Operation ≤ 20 seconds (see Note)	< 70% or > 120%		5%	5%	

Note: Further review by the respective Owner's Groups may determine that criteria for pump operation below 70% BEP may not be required, as the conditions are bounded by the set of criteria for the 70%-120% BEP range.

Gas Transport vs. Flow Rate

- Limit the allowable initial void



Simplified Equation To Limit The Initial Void
(Easy For Plant Implementation)

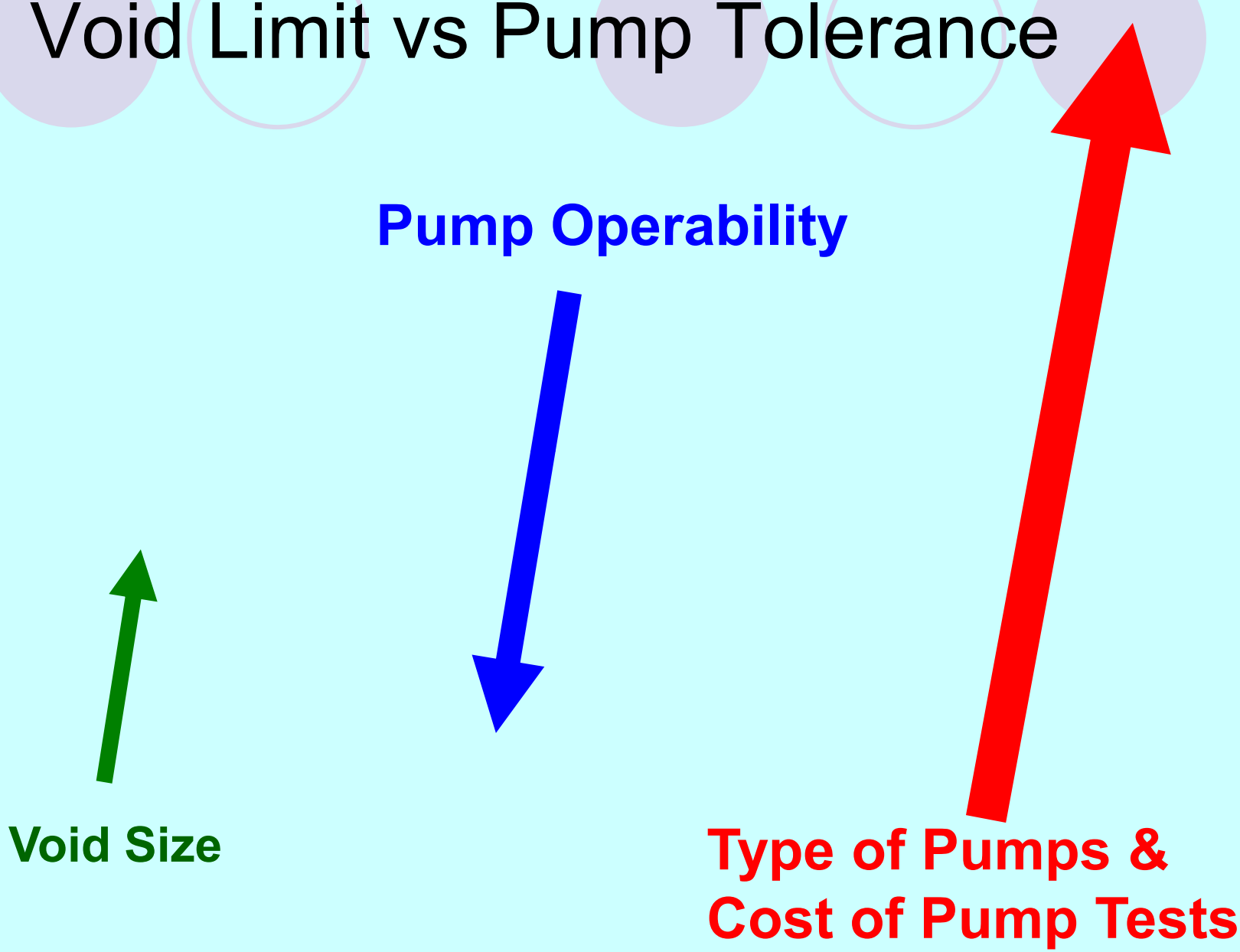
$$\mathbf{V}_{\textbf{allowable}} = Q_{max} \times \alpha \times \Delta t \times (P_p/P_1)$$

$\mathbf{V}_{allowable}$: Determines the Void Fraction

(If $\alpha \times \Delta t = 0$ ➔ No void at all)

What are the appropriate **α & Δt** → **Gas Volume ?**

Void Limit vs Pump Tolerance



Void Impact To the Pump

- Pump Performance Considerations
  - Relies on “incompressible” water to do work
    - Higher Void Fraction (less working fluid) ➔ Less TDH
  - Void expands as it approaches the eye of the impeller
    - P_{total} = Constant = $P_{Static} + P_{\frac{1}{2}\rho V^2} = P_{local} + P_{kinetic}$
    - As $P_{kinetic}$ increases, P_{local} decreases ➔ Void Vol. Increases
  - $P_{local} >> P_{vapor}$ ➔ Issue is not NPSHr (cavitation) but a flow passage issue
  - **Void Fraction To The Pump Must Be Limited**

Continuous Pump Test Curve

Ref: POWER 2009-81175

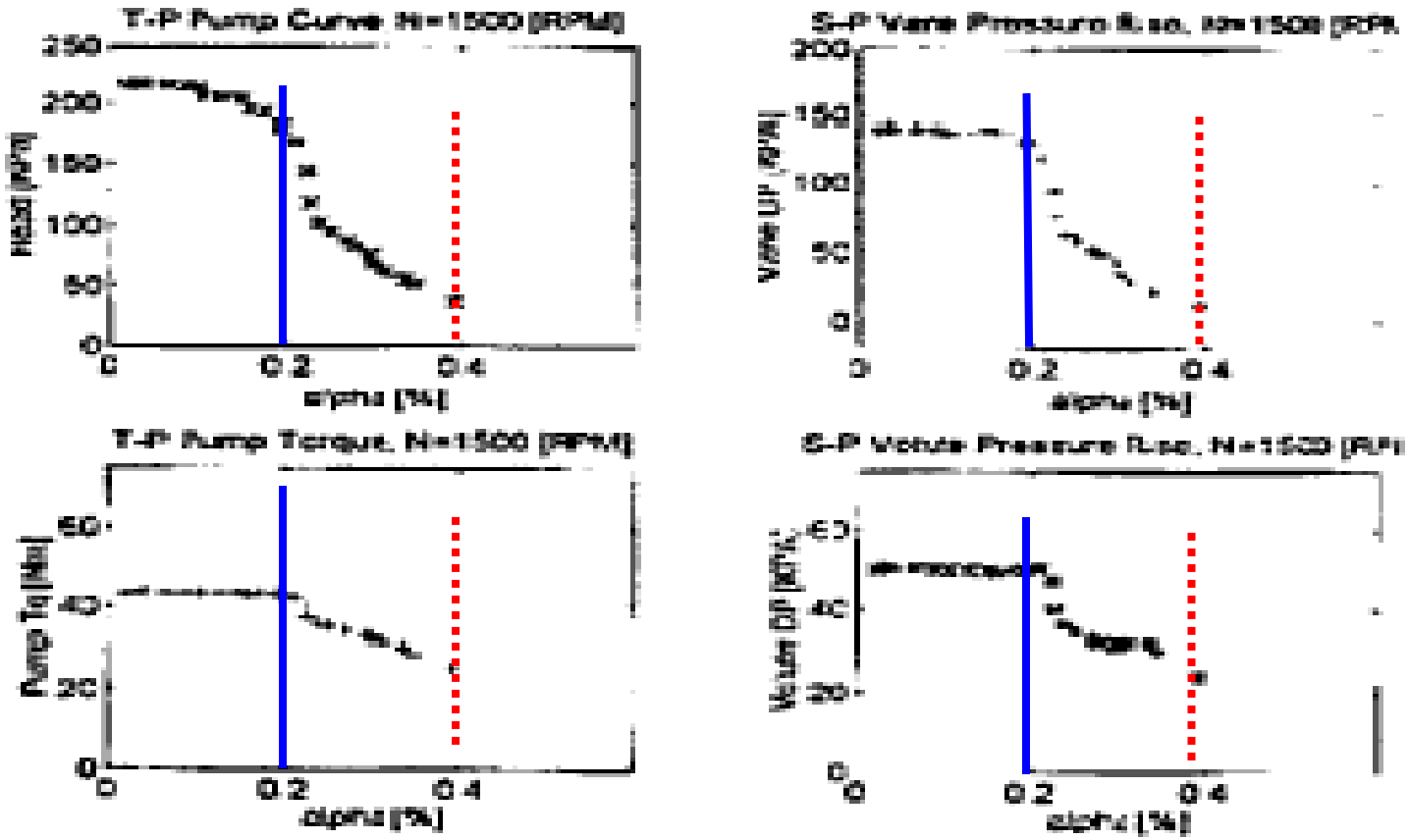


Figure 9. Two-phase flow pump torque and pressure distribution versus suction void fraction.

Continuous Pump Test Curve

(At least 3 test data points for a test curve)

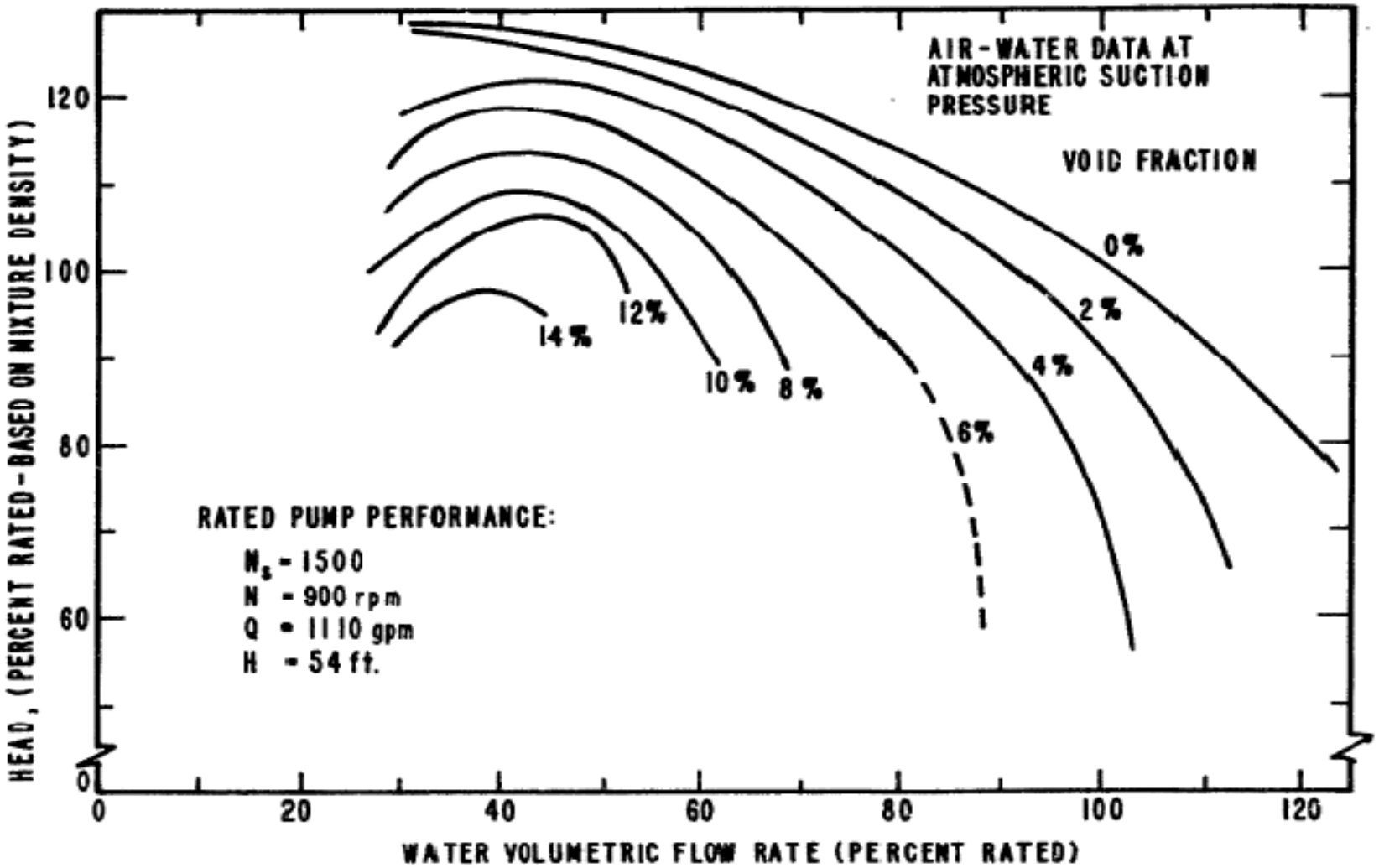


Figure 3-10 AIR/WATER HEAD CHARACTERISTICS AT ATMOSPHERIC SUCTION PRESSURE FROM STEPANOFF [14]

Ref: NUREG / CR 2792 Atmospheric Suction Pressure

Continuous Pump Test Curve

(At least 3 test data points for a test curve)

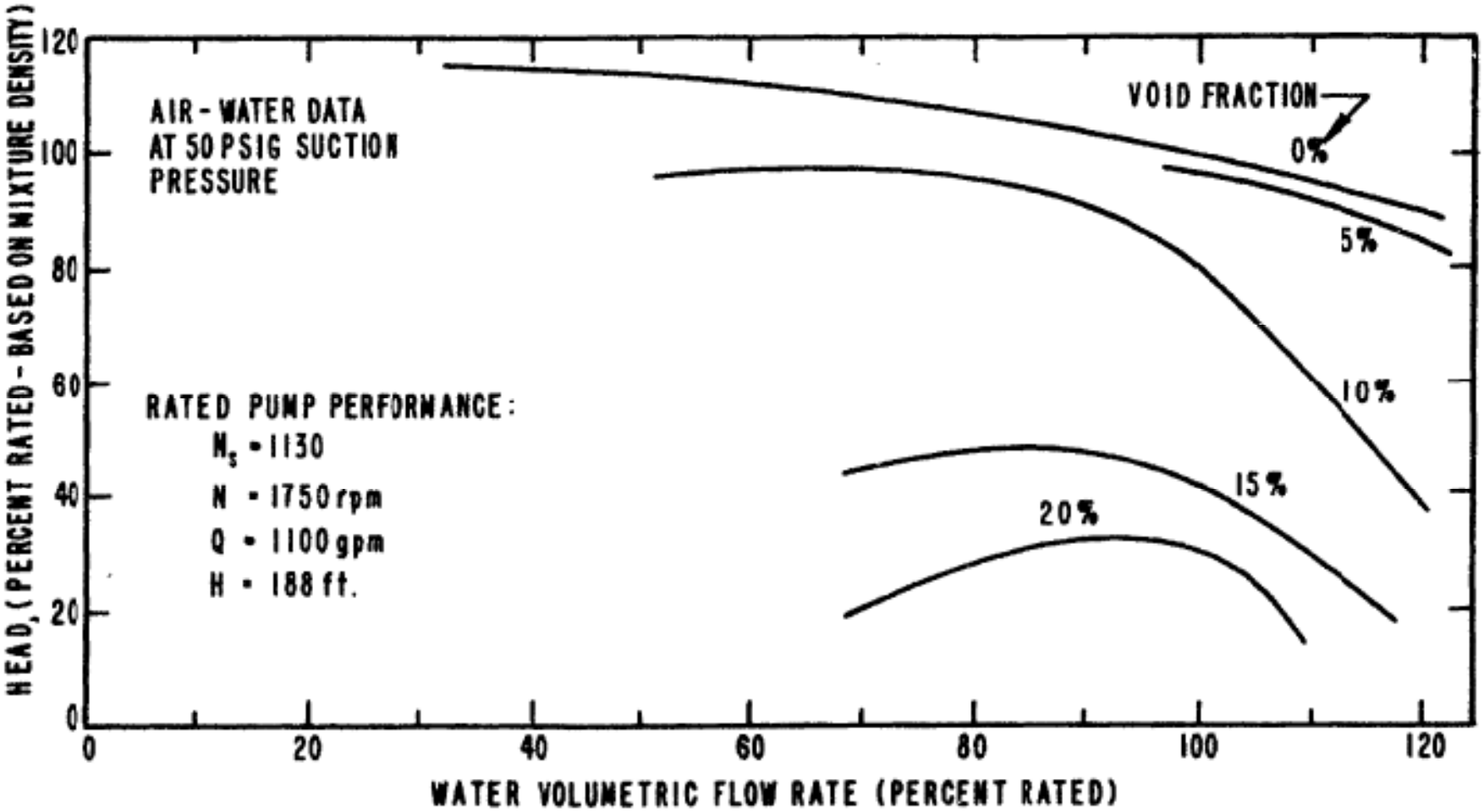


Figure 3-11. AIR/WATER HEAD CHARACTERISTICS AT 50 PSIG SUCTION PRESSURE FROM STEPANOFF [14]

Ref: NUREG / CR 2792 50 psig Suction Pressure

Multistage Is More Tolerant Than Single Stage Pump

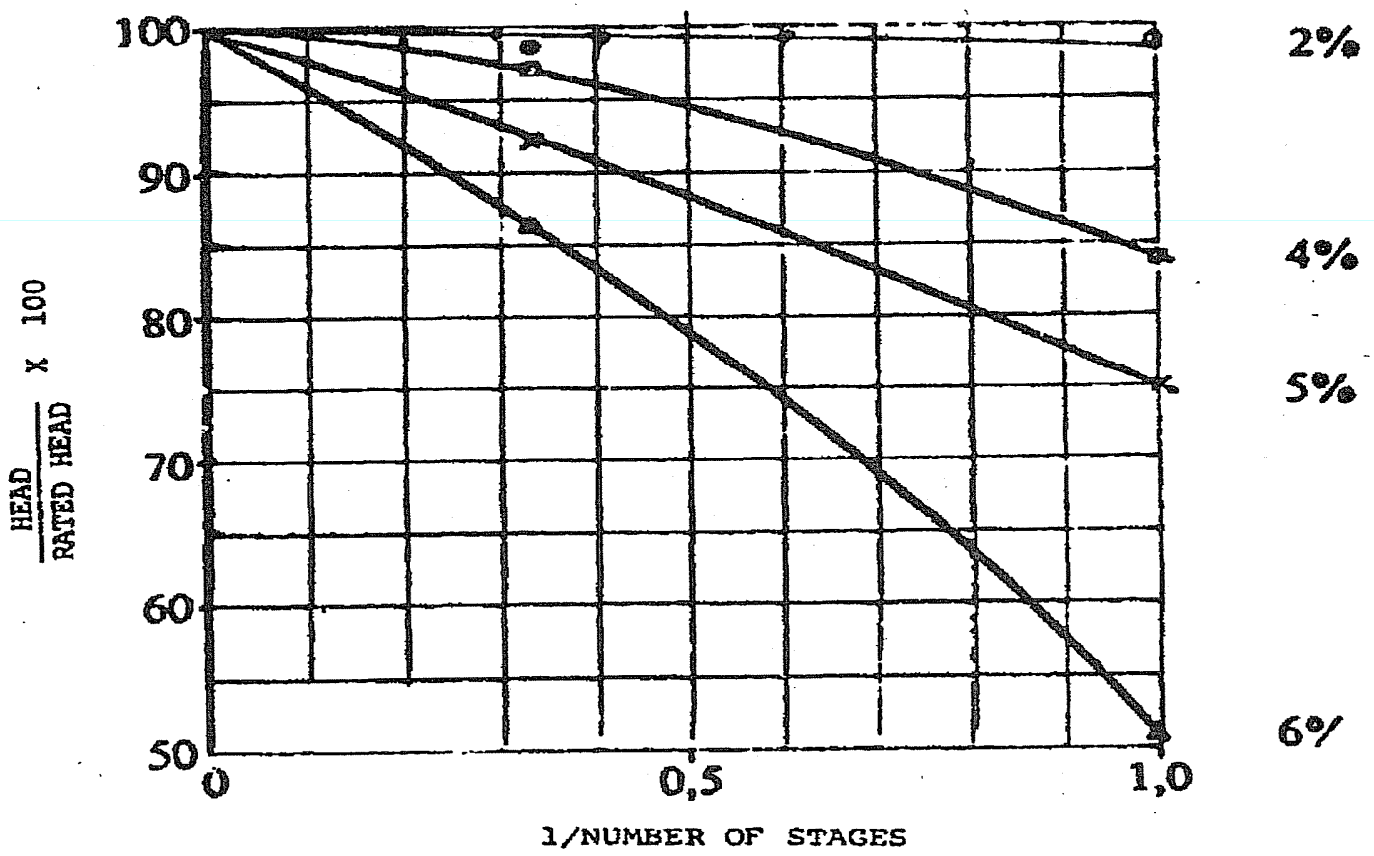


Figure 3-9. EFFECT OF NUMBER OF STAGES ON AIR/WATER PERFORMANCE FROM FLORJANCIC [32]

Ref: NUREG / CR 2792

Void Impact To the Pump

- **A Small, Limited Void Should Be Tolerable**
  - Pump Curve Typically Breaks Down After 20% - 40% void
  - Available Pump Tests Suggest Void Tolerance to 10% - 20% (based on the available suction pressure)
    - Effect Is a Continuous Degradation of the Pump Curve
    - The Pump Will Continue to Operate (No Gas Binding)

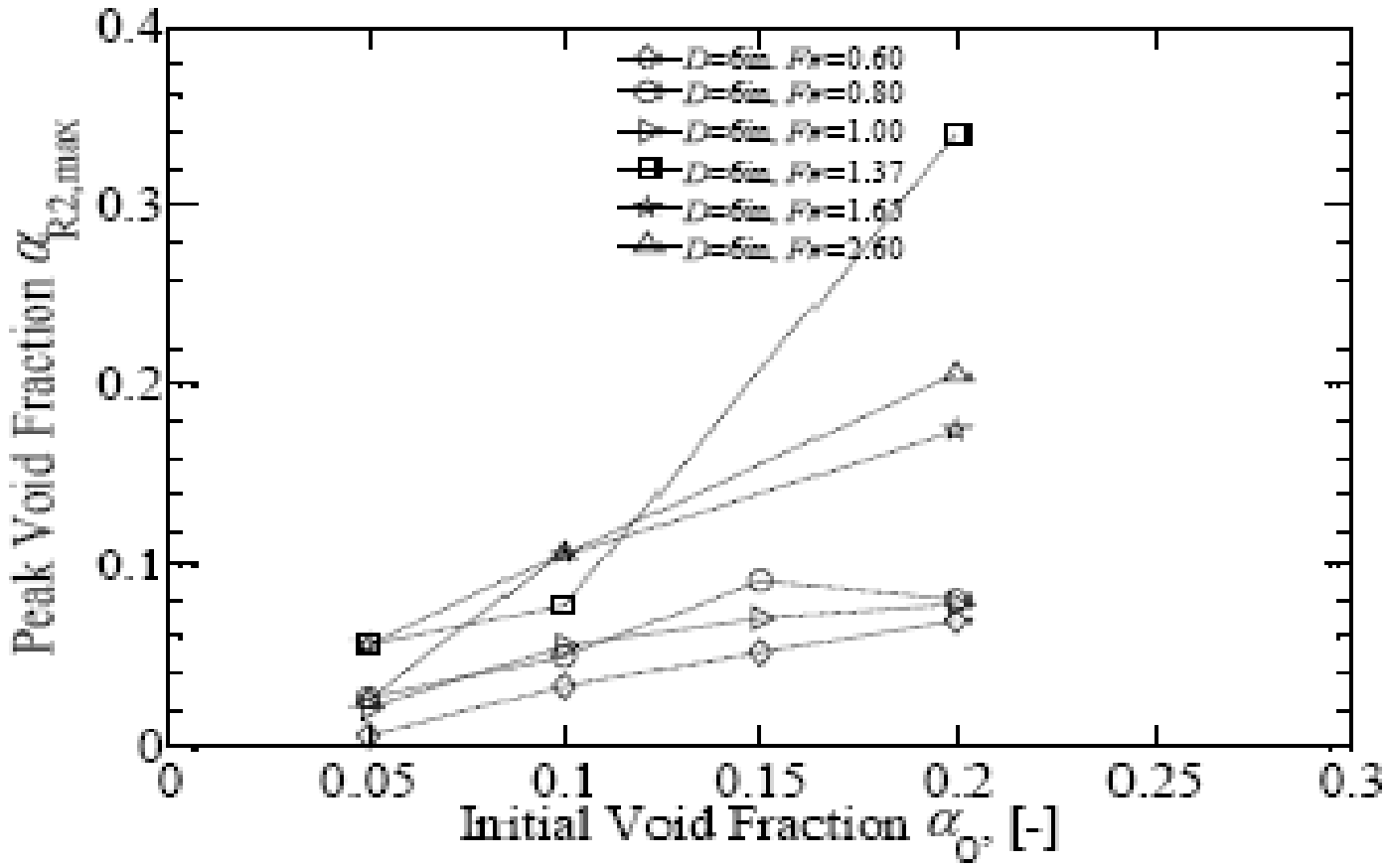
Void Impact To the Pump

- **A Small, Limited Void May Be Tolerable**
  - Pump Curve Typically Breaks Down After 20% - 40% Void
  - Available Pump Tests Suggest Void Tolerance Between 10% - 20% (based on the available suction pressure)
- **Simplified Equation**

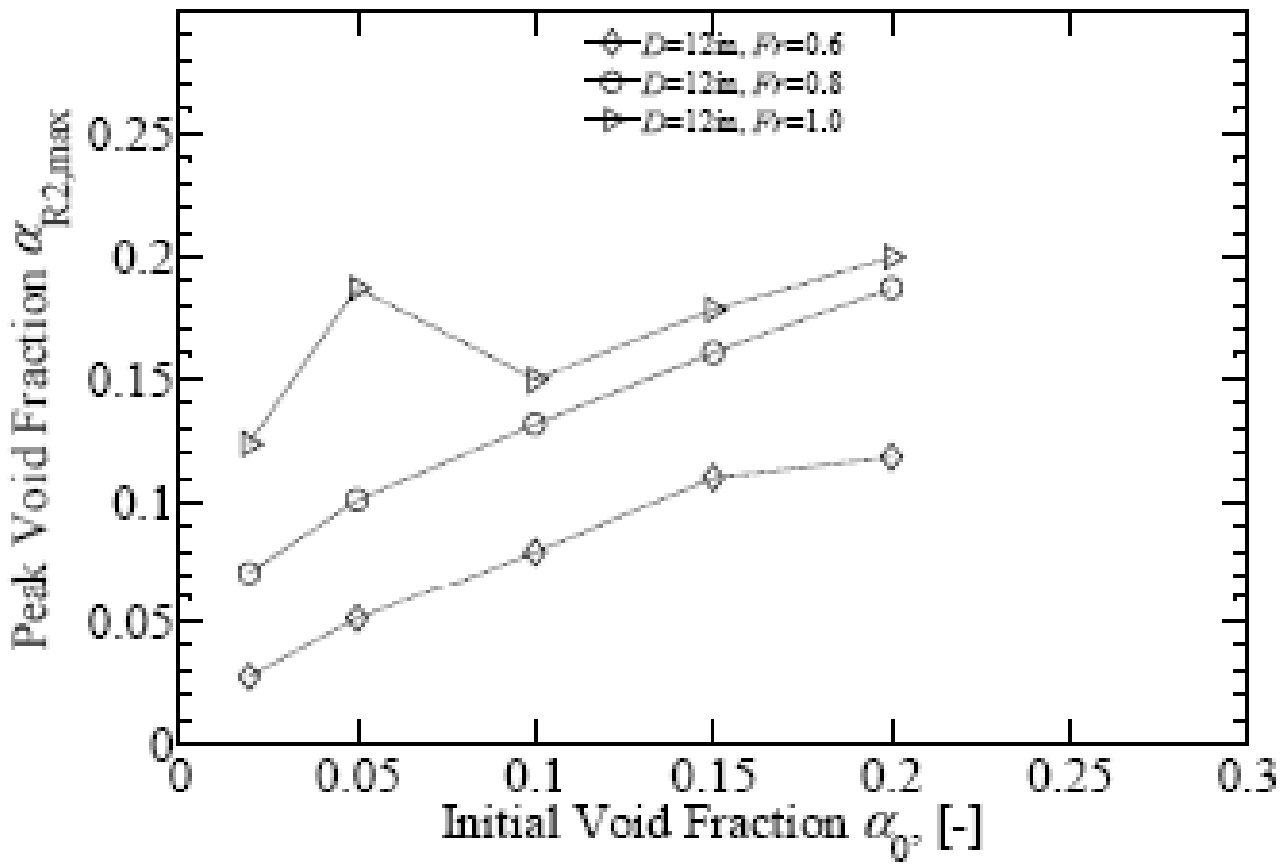
$$V_{allowable} = Q_{max} \times \alpha \times \Delta t \times (P_p/P_1)$$

- **Simplified Equation → Conservative Volume**
  - No Continuous Void Source in the ECCS
  - Void Passage Through Pump Is A Momentary Condition
  - ECCS Pumps have High Suction Pressure
    - Injection phase → full RWST static head
    - Recirc. Phase → Static head + containment P – screen ΔP

Peak Void from the 6” Loop Test



Peak Void from the 12” Loop Test

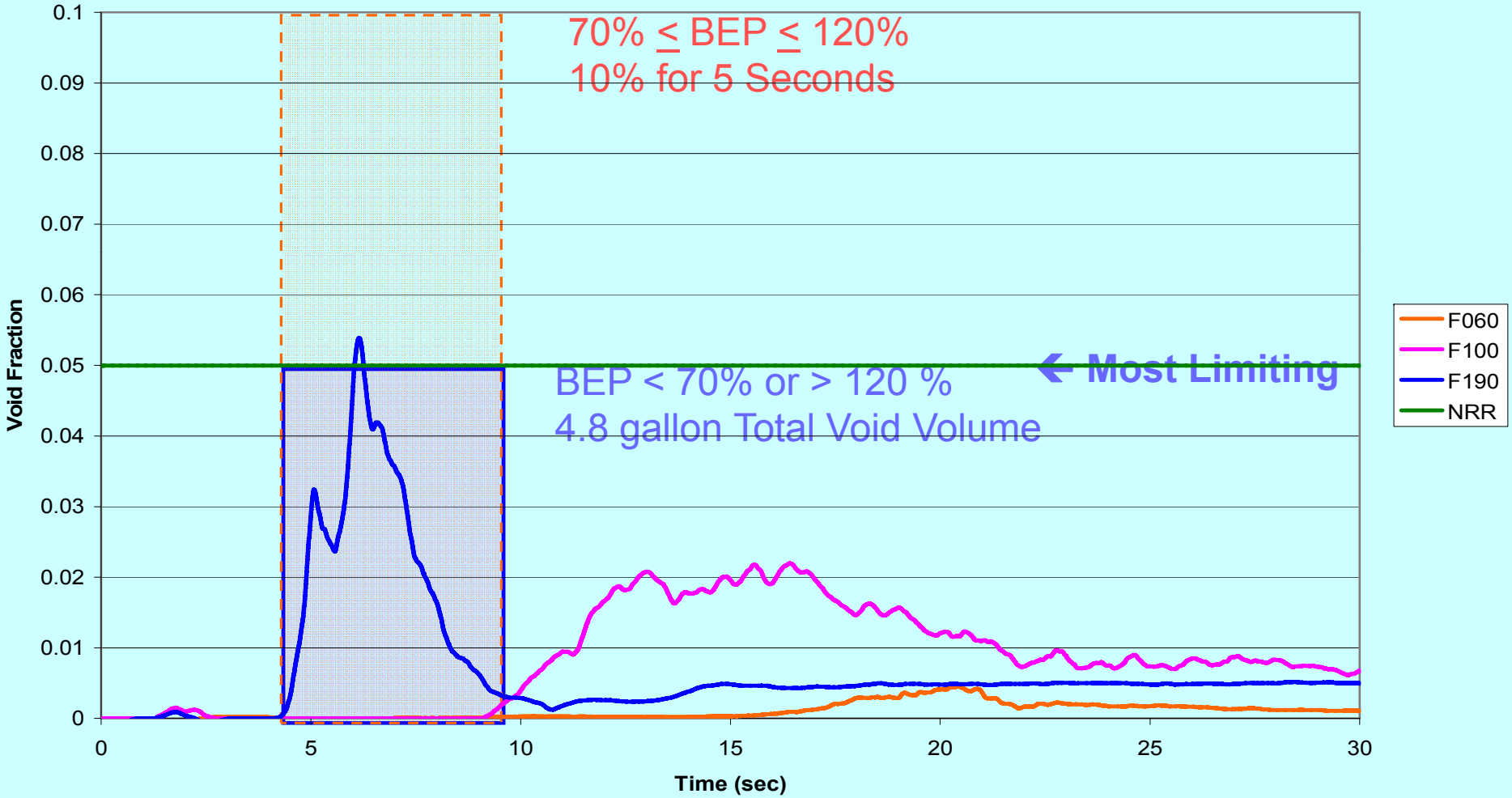


Identify the Maximum Flow Rate

ECCS Pumps	Suction ID (inch)	Q-max (gpm)	Fr -max
CCP	6.357”	560	1.37
SIP	6.357”	670	**1.64**
HPSI	10.25”	1410	1.05
RHRP	12.25”	4500	**2.14**
LPSI	18”	5500	**1.00**

Simplified Equation vs. DSS & APC

Figure 6
6 inch 5% initial void fraction RIMP2 **(11% initial void & Fr=1.9)**



Simplified Allowable Void Equation

- Static Void $\leq$ 5% for smaller pipes, $\leq$2% for larger pipes
- $V_{allowable} = Q_{max} \times \alpha \times \Delta t \times (P_p/P_1)$

Pipe ID	α	Δt	X-Section (Static Conditions)
< 12”	10%	5 second	$\leq$ 5%
$\geq$ 12”	2%	20 second	$\leq$ 2%

Examples of Allowable Void From The Simplified Equation

- Static Void $\leq$ 5% for smaller pipes, $\leq$2% for larger pipes
- $V_{allowable} = Q_{max} \times \alpha \times \Delta t \times (P_p/P_1)$

Pumps	Q_{max}	α	Δt	$V_{allowable}$	X-Section
CCPs	560	10%	5 second	4.67 gal	$\leq$ 5%
SIPs	670	10%	5 second	5.58 gal	$\leq$ 5%
RHRPs	4500	2%	20 second	30 gal	$\leq$ 2%
HPSI	1800	10%	5 second	12 gal	$\leq$ 5%
LPSI	5500	2%	20 seconds	36 gal	$\leq$ 2%

Purdue -8 psig: 5% → 4.8 gal & 10% → 9.7 gal

Treatment of the Simplified Equation

- Supply Headers with Takeoffs
  - Calculate allowable volume for each individual pump suction
  - Apply smallest of the allowable branch line limits to the header
- Vertical pipe volume > 4 X Void volume
- Allowable void accounts for static pressure change between high point and pump suction
  - Elevation change must be $\geq$ 10 feet

Advantages of the Simplified Equation

- Simplified Equation is Conservative
  - Limits The Allowable Void Volume
  - Allowable Void volumes < Purdue Tested
  - Not Likely To Gas Bind The Pump
  - Provides Reasonable Basis for Pump “Operability”
  - Reasonable Engineering Judgment
  - Enveloped by DSS / APC Void Criteria
  - Supported by the Purdue Test Data
- Easily Implemented In ECCS Surveillance Acceptance Criteria
  - Simple Method to Define Allowable Void Volume