Inerting a B-747 SP Center Wing Fuel Tank Scale Model with Nitrogen Enriched Air

FAA

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Outline

- Background
- Model
- Instrumentation
- NEA Distribution
- Equations
- Test Data
- Summary

Scale Fuel Tank Inerting

Background

- FAA is Seeking to Improve Upon Existing Fuel Tank Safety in Fleet in the Wake of TWA800 Air Disaster
- Inerting of Fuel Tanks Could Provide Significant Fuel Tank Protection. Most Available Data on Fuel Tank Inerting for Rectangular Box
- Focus of the Testing is to Validate Existing Assumptions for Inerting Complex Geometric Spaces (Commercial Transport Fuel Tanks) as Compared to Simple Rectangular Boxes
- Also, Use Model to Determine the Most Efficient Deposit Configuration

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Description of Model

- Quarter-Scale Model of Boeing 747 SP CWT was Built from Three Quarter Inch Plywood By Scaling Drawings from Shepherd Report
  - 24% length Scale (1.2% Volume)
- Spars and Spanwise Beams Simulated with Quarter Inch Plywood Installed in Slats with Scaled Penetration Holes
- Vent System Simulated with PVC Tubing Plumbed to an Aluminum Vent Channel Adhered to a Plywood Top
- Removable Lid to Allow for Model Maintenance and Modification

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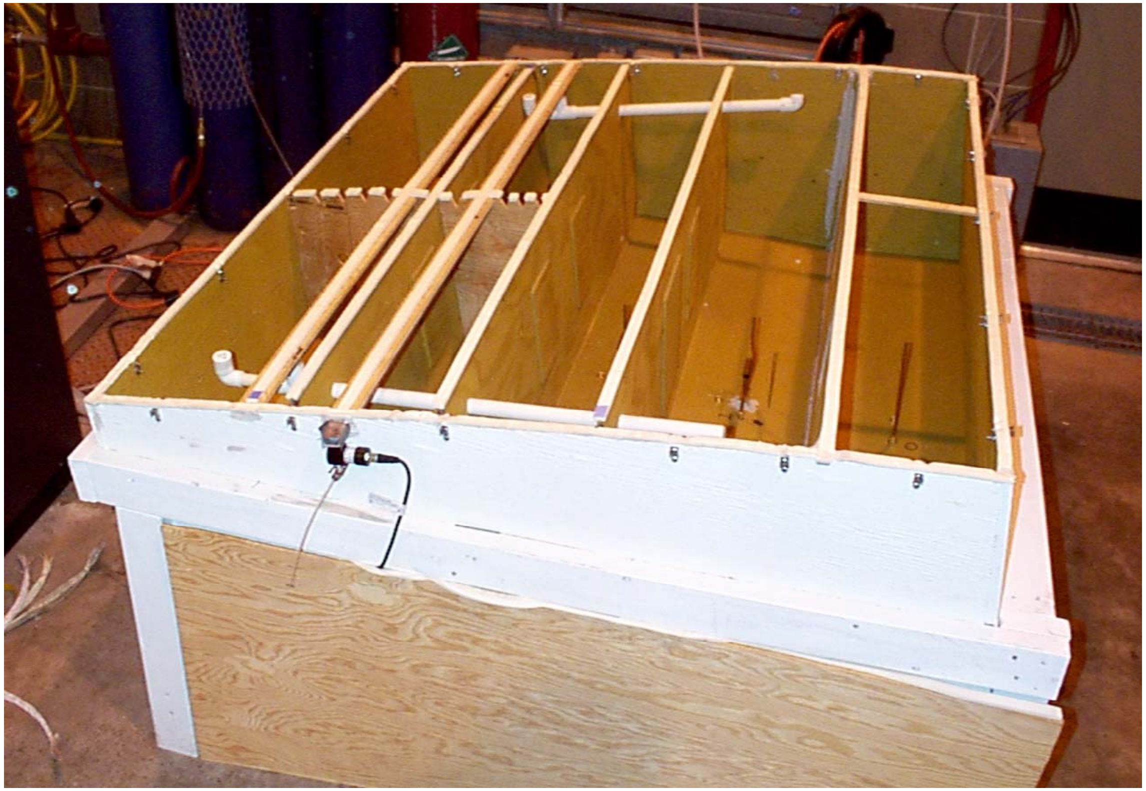
Photo of Model



Instrumentation

- Oxygen Sensor in Each Bay and in One Vent Channel
  – Sample Returned to Each Bay to Have Minimal Effect on Inerting Process
  – Sensors Plumbed in Unique Sample “Drafting” Method
  – Sensor Remote From Analyzer
- Thermocouple in Each Bay to Detect Temperature Changes During Testing
- NEA Generator Equipped with Oxygen Analyzer
  – Calibrated and Checked before Each Test
  – Used to Calibrate all Other Sensors

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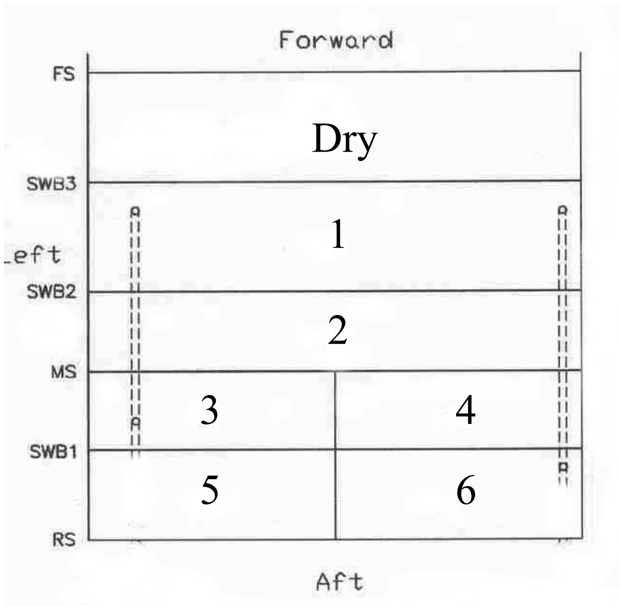
B-747 SP Bay Diagram with Volume Data



Bay	Calculated Volume	Scaled Value	Percentage of Tank		Sheppard Volume	Percentage Volume
0(dry)	546.1	7.549	n/a		536.7	n/a
1	577.7	7.986	31.2%		543.9	30.7%
2	421.1	5.823	22.7%		392.0	22.2%
3	188.2	2.602	10.1%		196.0	11.1%
4	188.2	2.602	10.1%		196.0	11.1%
5	239.6	3.312	12.9%		220.7	12.5%
6	239.6	3.312	12.9%		220.7	12.5%
Total	1854.4	25.637	100%		1769.3	100%

Reported Volume = 1775

Percent Difference = 4.47 %

NEA Distribution System

- “Variable Manifold” Allows for Depositing NEA in Any and All Bays of the Tank at Different Flow Rates
  - Accepts Output of NEA Generator and is Plumbed to a Bank of Flow Meters
  - Two Flow Meters in Parallel for Each Bay to Allow for Both Large and Small Deposit Quantities
  - Measure Meter Back Pressure for Accurate Flow Reading
- Used Directing Nozzles on NEA Deposit Fittings for Some Uneven Deposit Cases

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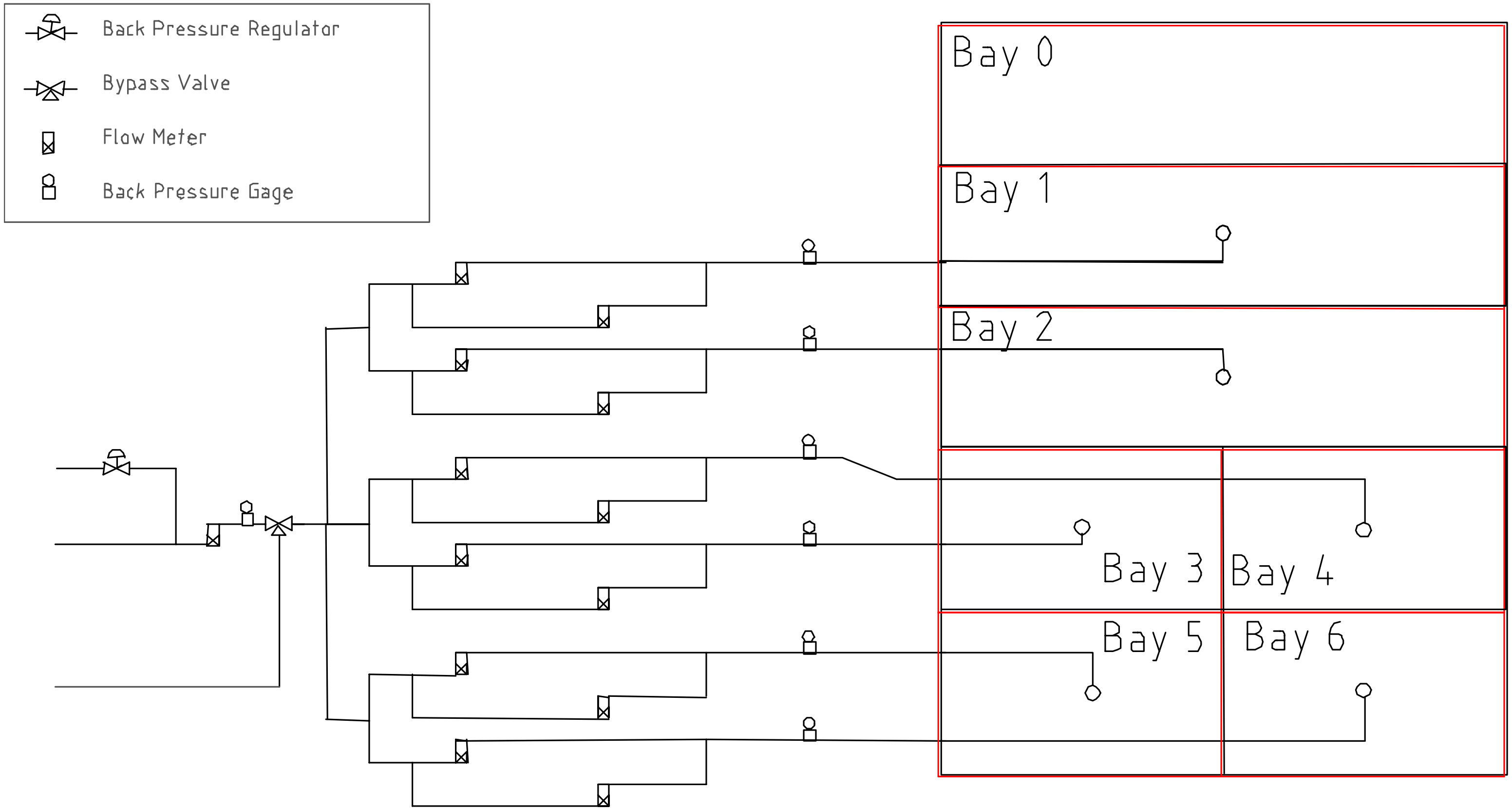
NEA Distribution System Diagram



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Equations Used

Volumetric Tank Exchange (VTE)

$$Volumetric\ Tank\ Exchange = \frac{Time * Volume\ Flow\ Rate}{Fuel\ Tank\ Volume}$$

Weighted Volumetric Average

$$Volumetric\ Average = \frac{7.986[O_2\ Bay1] + 5.823[O_2\ Bay2] + 2.602[O_2\ Bay3] + 2.602[O_2\ Bay4] + 3.312[O_2\ Bay5] + 3.312[O_2\ Bay6]}{25.637}$$

Inerting Solution (Perfect Mixing)

$$O_2(t) = O_{2\ Amb} - [(O_{2\ Amb} - O_{2\ NEA})(1 - e^{-VTE})]$$

Empirical Solution (FAA Ullage Washing Data)

$$O_2(t) = O_{2\ Amb} - [(O_{2\ Amb} - O_{2\ NEA}) *$$

$$(-0.0145\text{VTE}^4 + 0.1345\text{VTE}^3 - 0.5275\text{VTE}^2 + 1.0873\text{VTE} - 0.0121)]$$

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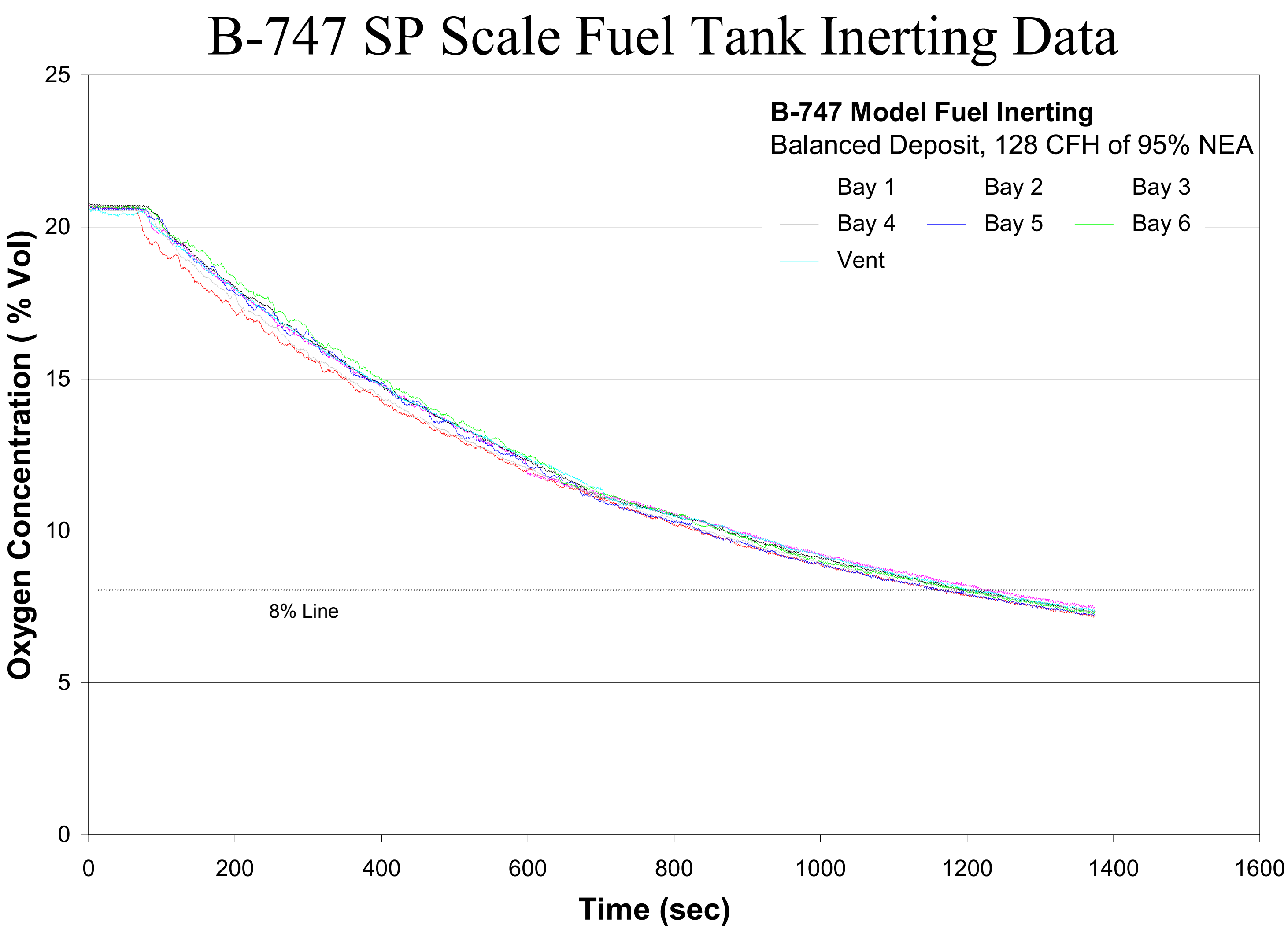
Cross-Vented Configuration Data

- Inerted Tank Several Times with Different NEA Oxygen Concentrations with the Goal of Balancing the Flow into Each Bay to Obtain “Equal Inerting”
- Used the Volumetric Average Developed to Make Comparisons with Other Inerting Runs
- Results As Expected and Consistent with Previous Testing but New Numbers Point Toward a VTE of 1.6 for 95% NEA
- Depositing in and Uneven Manner Can Simplify Manifold and Have No Negative Impact on the Inerting Process

Scale Fuel Tank Inerting



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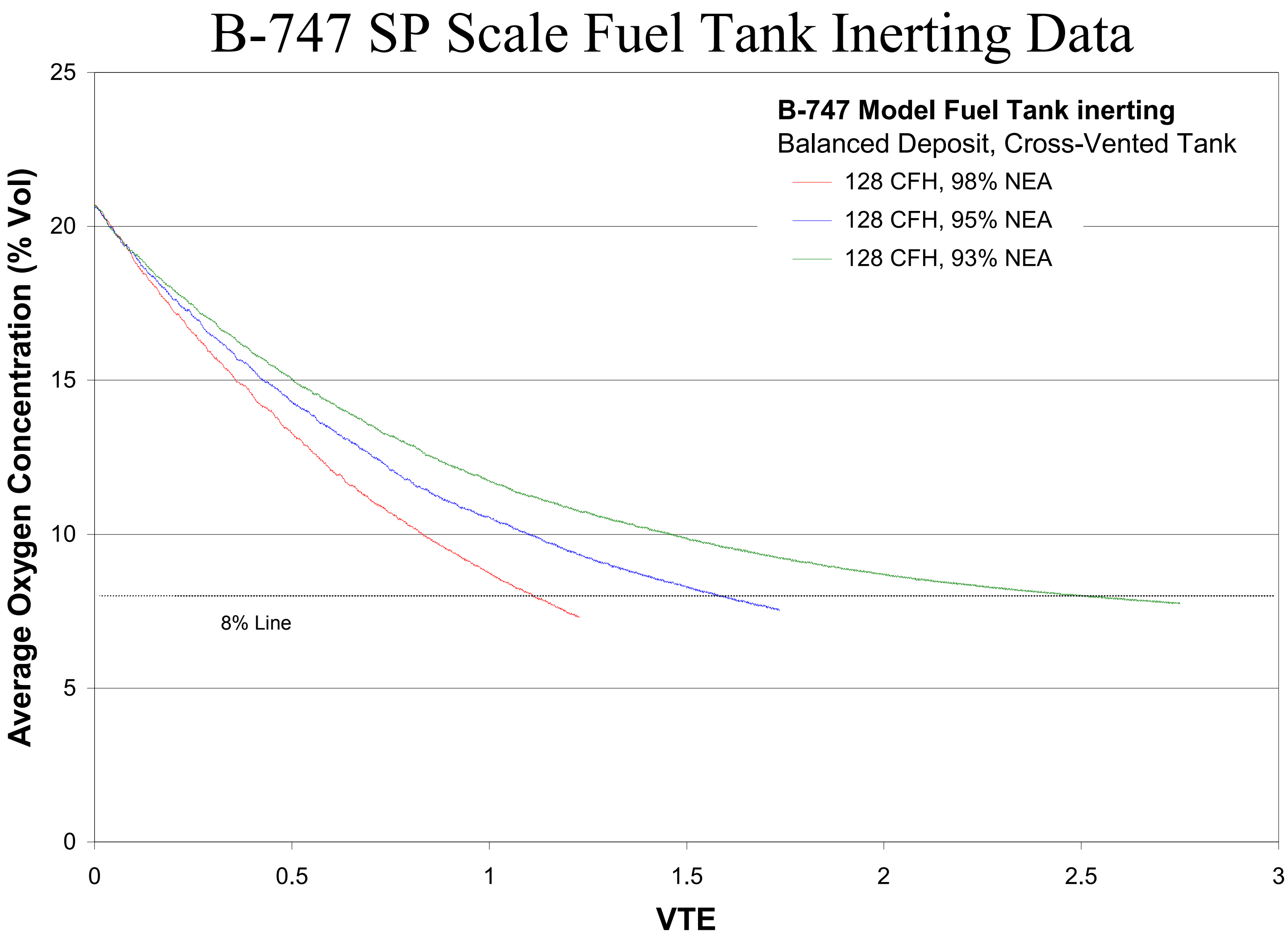

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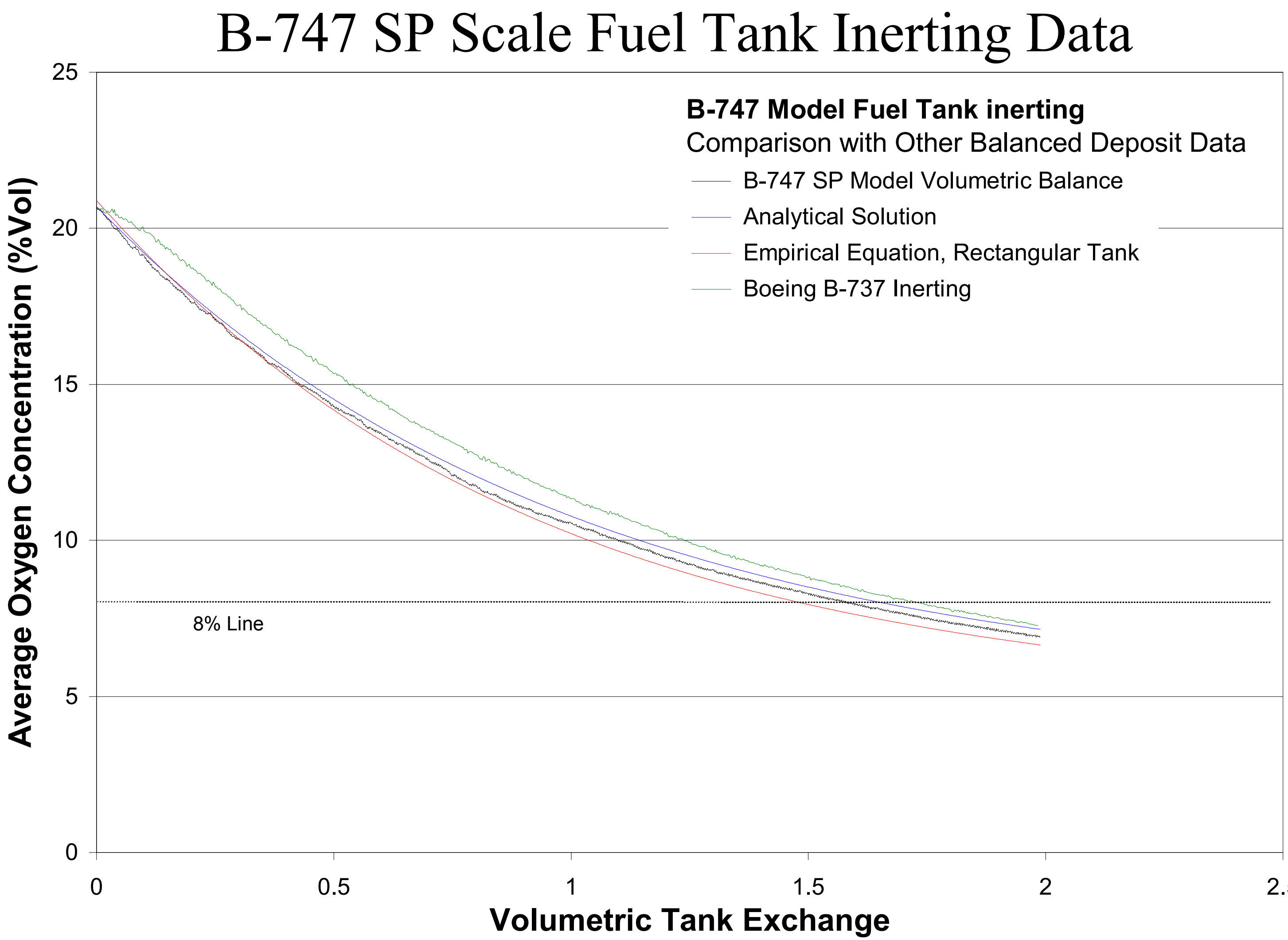

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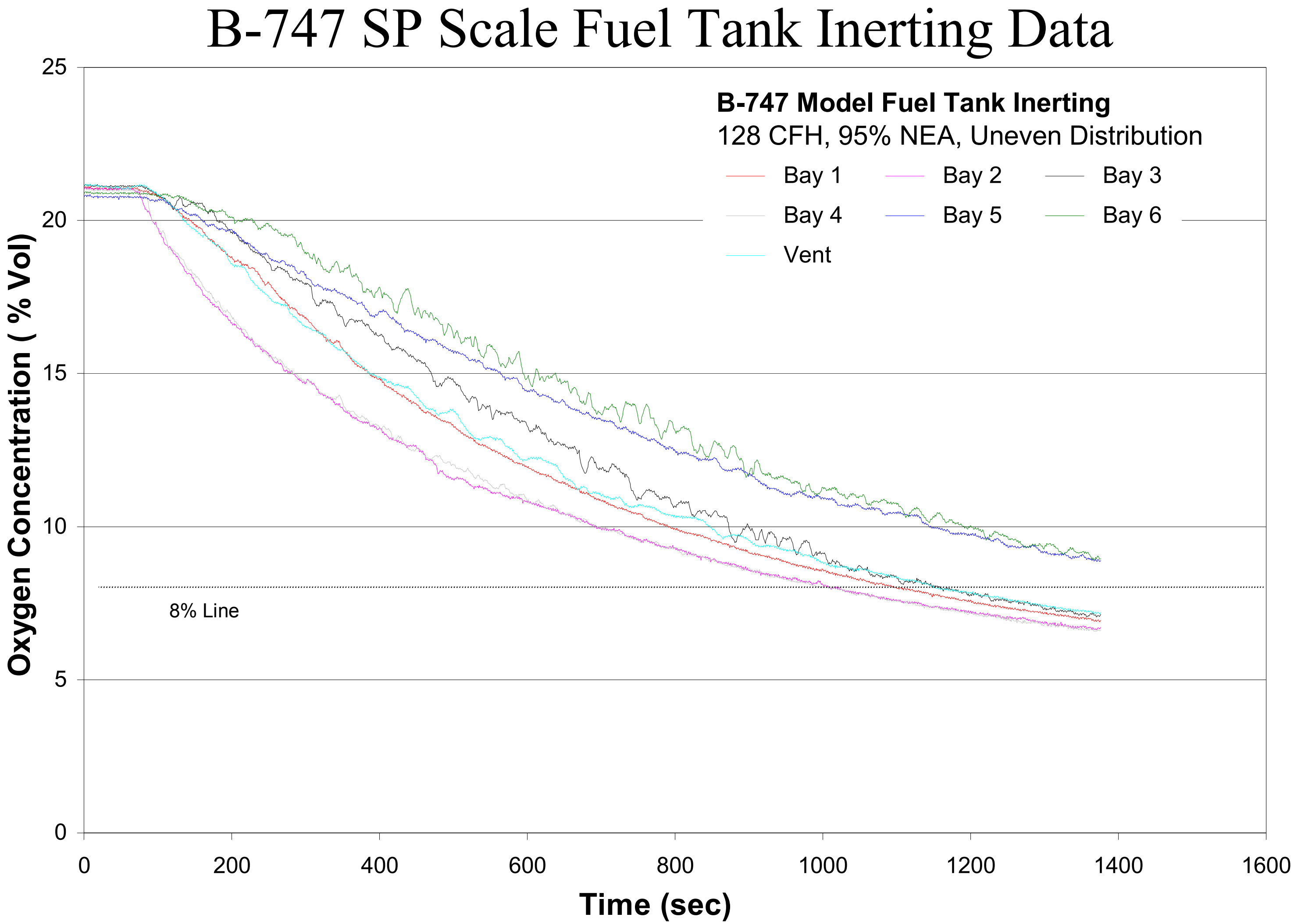

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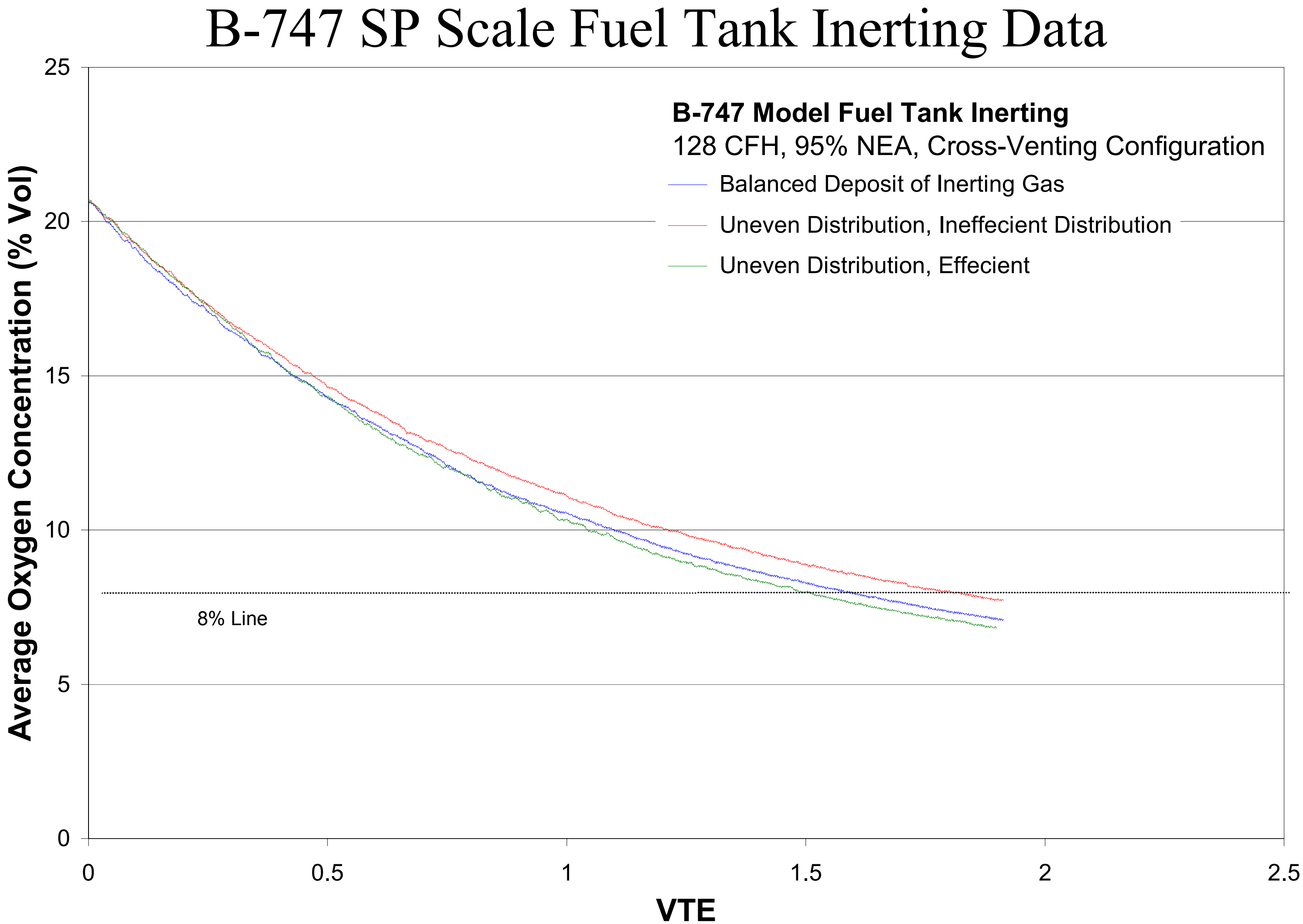

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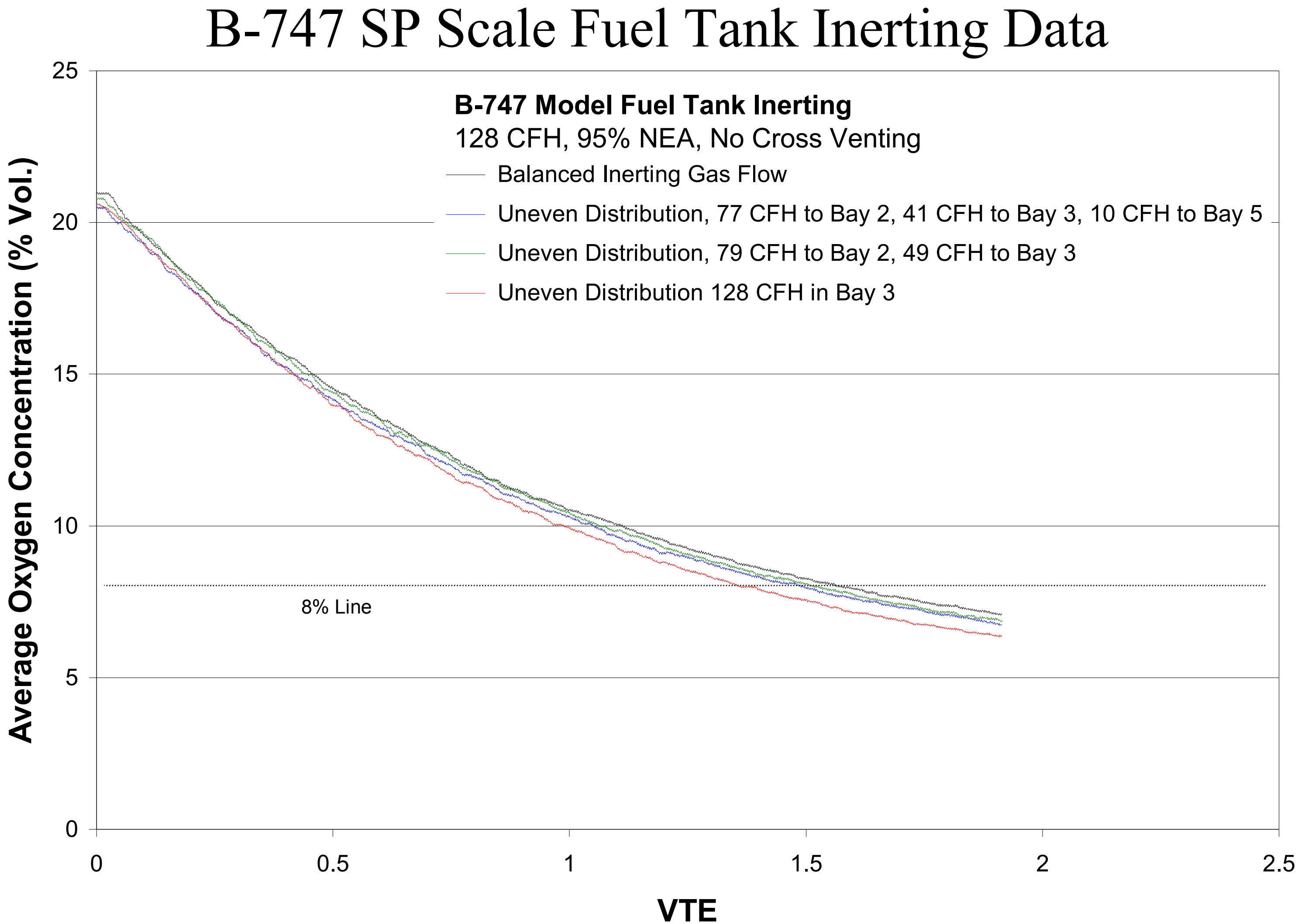
Blocked Vent Configuration Data

- Inerted Tank Several Times with NEA 95% to Minimizing the NEA Volume Required to Inert the Tank with Left Half of Vent System Blocked (No Cross Venting)
  - First did Balanced Run to Give Baseline; Used the Volumetric Average Developed to Make Fair Comparisons with Other Methods
- Results Illustrated Modest Improvement with Simplest Deposit Scheme
  - Deposit Scheme Has Poorer NEA Distribution But Data Indicates Oxygen Concentration From Bay to Bay Will Diffuse
  - Method Does Not Appear to Be Sensitive to Flow Rate and NEA %
- Comparisons with Full-Scale Data Marginal, VTE Consistent

Scale Fuel Tank Inerting



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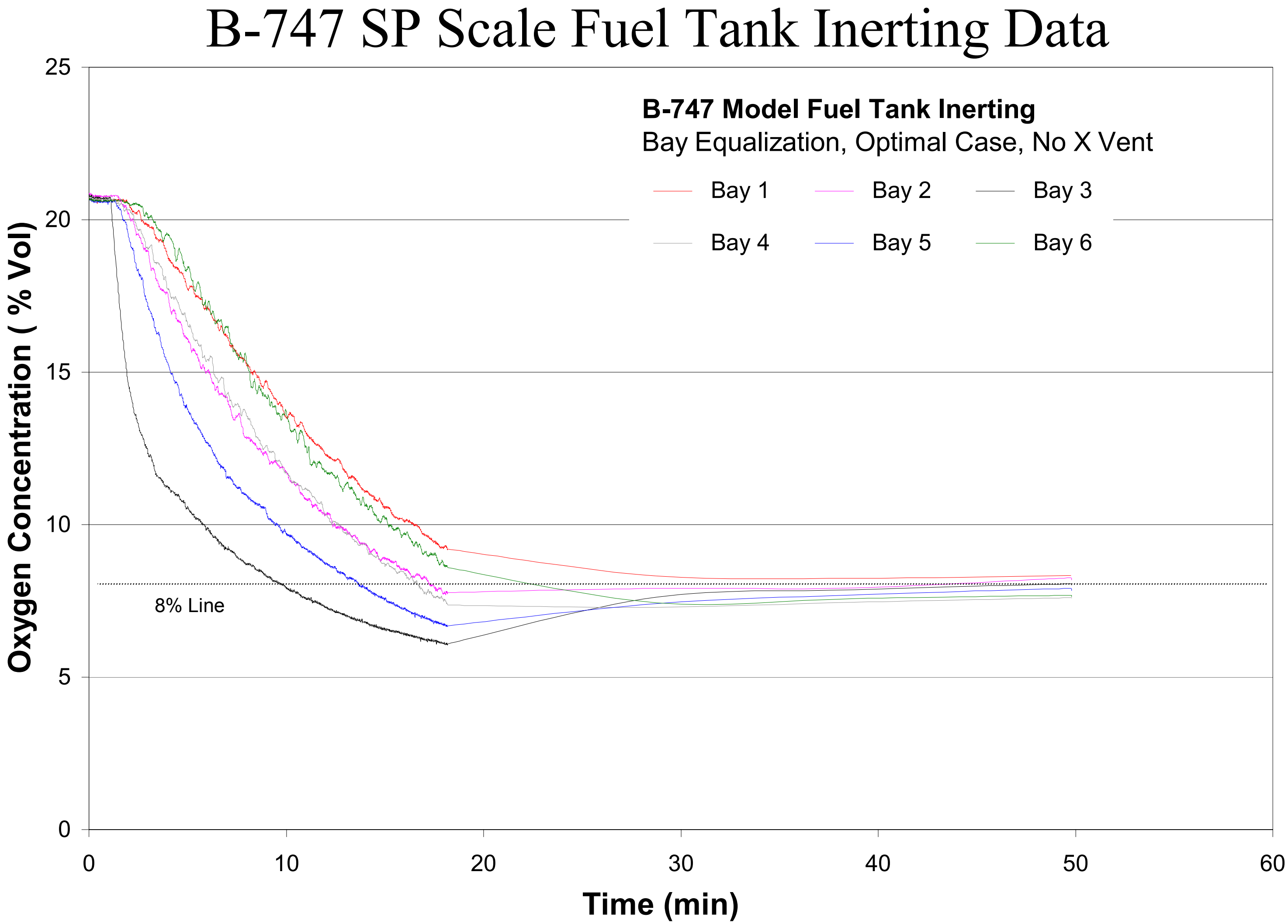

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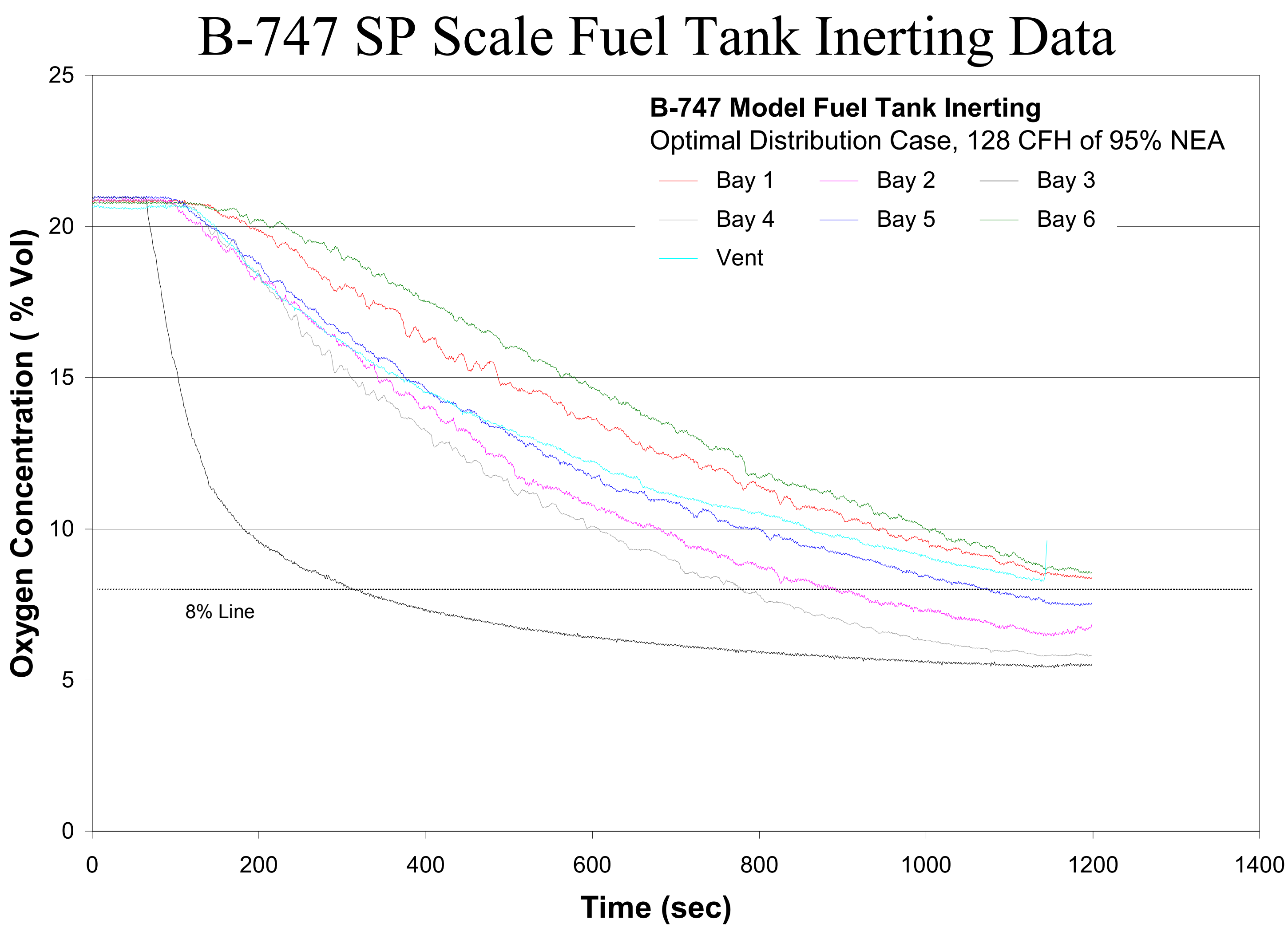

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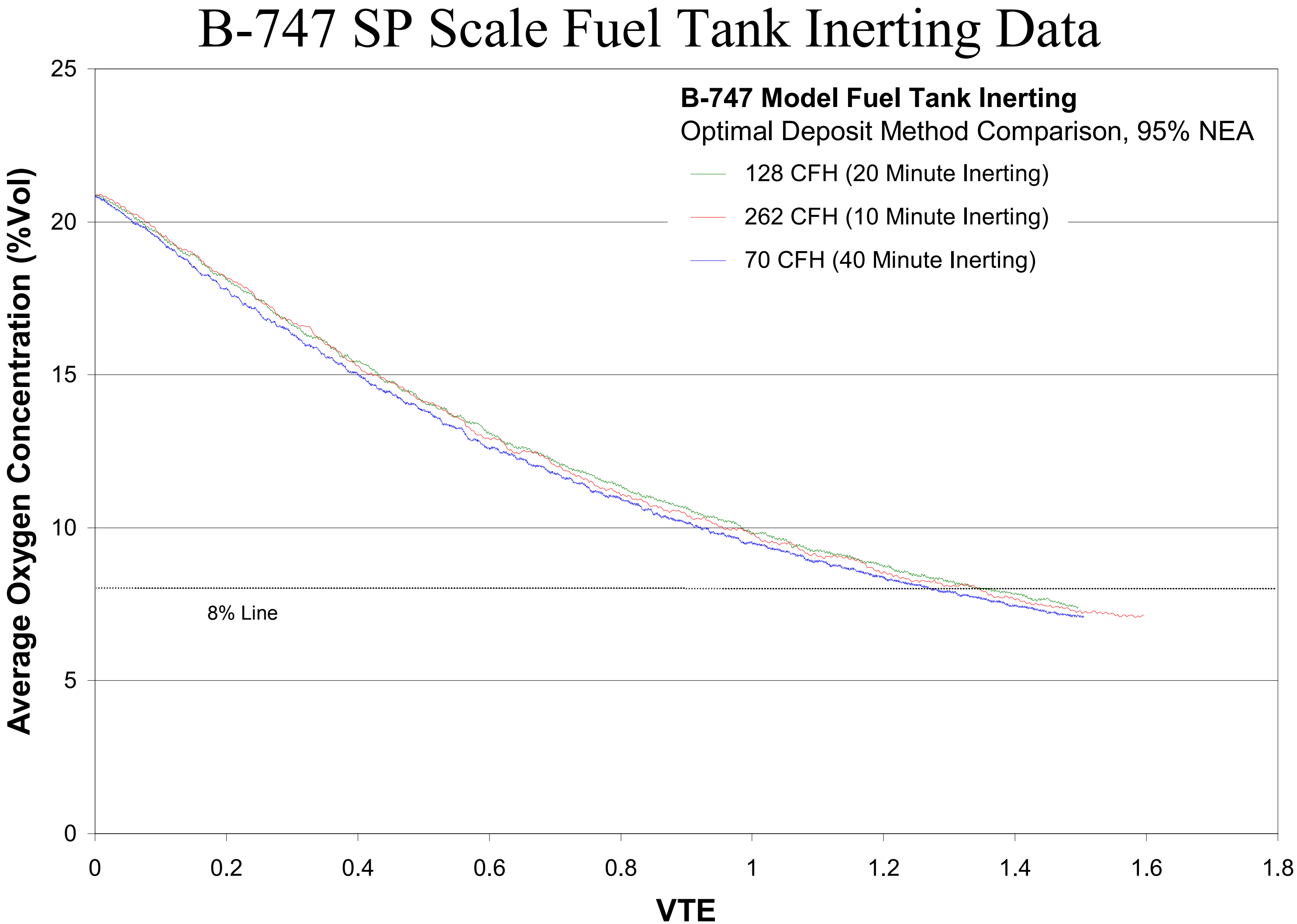

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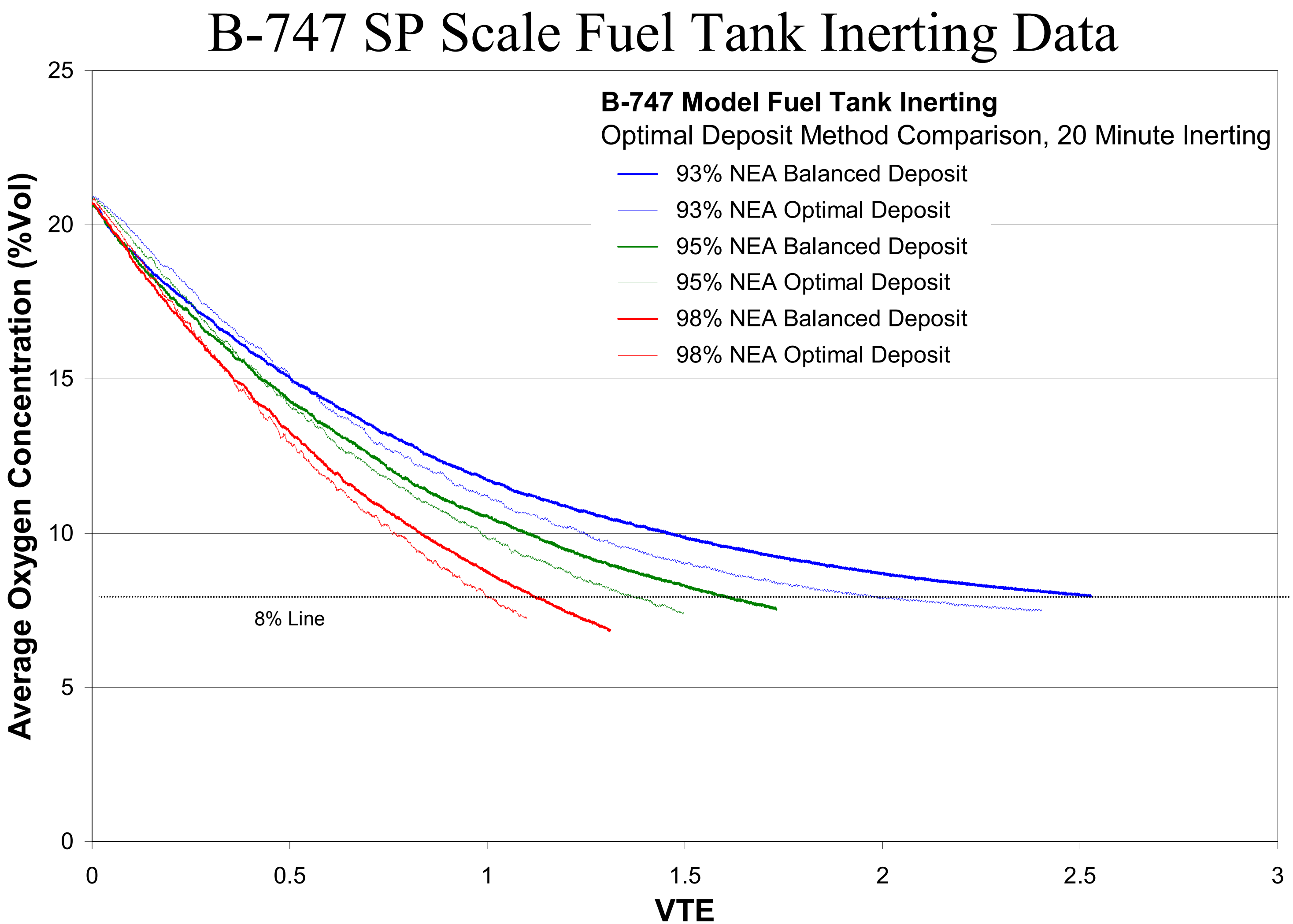

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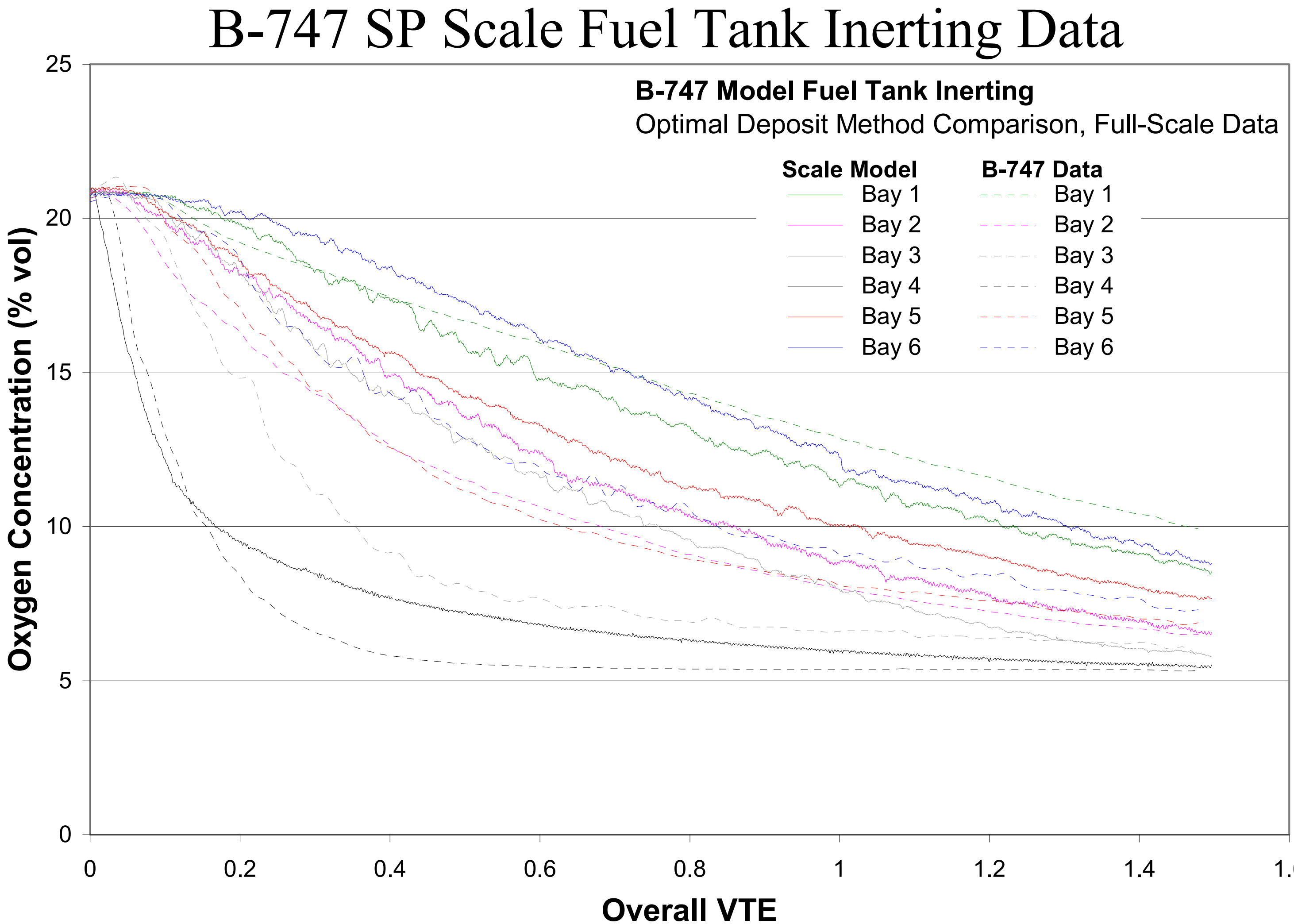

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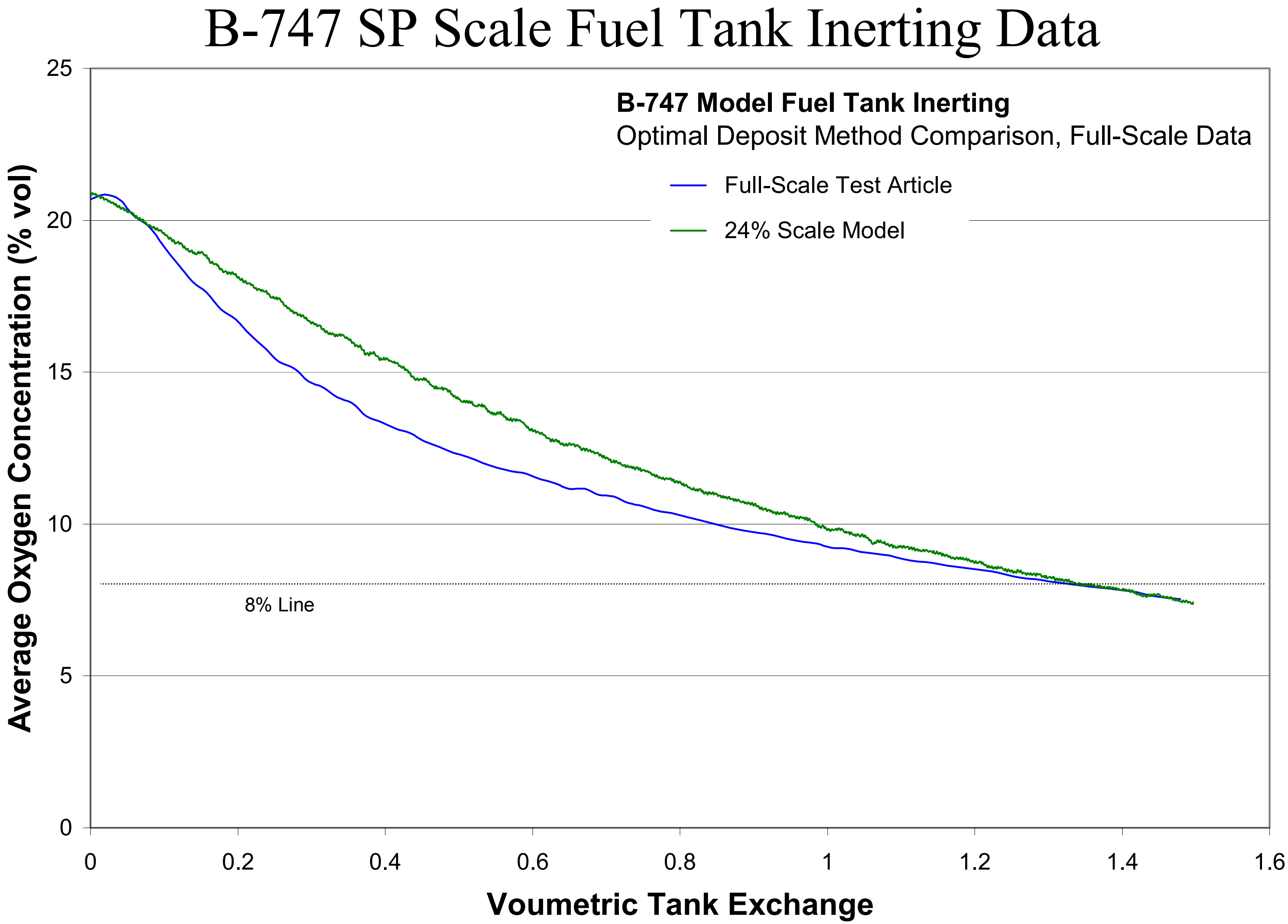

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Summary

- Model Results Consistent with Existing Knowledge Base But VTE Slightly Higher Then in Original FAA Experiments
  - This is Believed to be due to Better Measurement Techniques Developed
- Depositing in an Efficient Manner Can Greatly Simplify Manifold Design and Even Improve Inerting Efficiency
- Initial Full-Scale Test Article Data Highlight Potential Deficiencies with this Design Methodology. More Testing Needed to Verify the Limitations of Scale-Model Inerting Evaluation