API RP 1175
Pipeline Leak Detection-Program Management Workshop

Safety Message

Wednesday and Thursday, April 26th and 27th, 2017

ONAGAWA VS. FUKUSHIMA POWER STATIONS

- The difference in outcomes at the two plants reveals the root cause of Fukushima Daiichi's failures: the utility's corporate "safety culture."

MOST SIGNIFICANT QUOTE:

- "The earthquake and tsunami of March 11, 2011, were natural disasters of a magnitude that shocked the entire world. Although triggered by these cataclysmic events, the subsequent accident at the Fukushima Daiichi Nuclear Power Plant cannot be regarded as a natural disaster. It was a profoundly manmade disaster—that could and should have been foreseen and prevented."
- —Kiyoshi Kurokawa, "Message from the Chairman," *The Official Report of The Fukushima Nuclear Accident Independent Investigation Commission*

Related facts

- Fukushima - Daiichi
  - Initial Construction 1967;
  - Initial start, first of 6 units in 1971 – last unit started in 2010; All Boiling Water Reactors
  - 60 km further away from epicenter – South of Onagawa
  - Excavation 25 m lower – easier construction, lower sea-wall
  - Lobbied against further safety actions

- Onagawa
  - Groundbreaking in 1980; Last unit started 2002.
  - Three units – All Boiling Water Reactor type
  - Fastest construction of any Nuclear Power Station
  - Closest Nuclear Power Station to epicenter
  - Higher sea-wall, deeper cooling, higher elevation
  - Continued to verify design assumptions

SAFETY CULTURE

- Fukushima Daiichi
  - Owned by Tokyo electric (TEPCO)
  - “It is evident that safety protocol was neglected when making decisions, and because TEPCO were monopolizing the market, most people had the cavalier mentality that “nothing will go wrong”, thus spent little time considering safety.”

- Onagawa
  - Owned by Tohoku Electric
  - “Yanosuke Hirai, the Vice President of Tohoku Electric Power Company from 1960 to 1975, was very adamant about safety protocols, and continued to insist on prioritization of safety regardless of constant disagreement.” (Died in 1986)

PRIOR TO THE DISASTER

- Fukushima Daiichi

  - The company had a mindset that its domination in the electricity industry was an indication of flawlessness. After the disaster, Hasuike Tooru, the former president of Tepco, described how management decided to lengthen the expected lifetime of power plants, even if there were potentially severe safety consequences.

- Onagawa

  - Representatives of Tohoku Electric participated in seminars and panel discussions about earthquake and tsunami disaster prevention held by the Japan Nuclear Energy Safety Organization.
  - The company implemented strict protocols and drills for disaster response, and all workers were familiar with the steps to be taken when a tsunami was approaching.

DURING AND AFTER THE EARTHQUAKE

• Fukushima Daiichi

- The active reactors automatically shut down their sustained fission reactions. However, the tsunami destroyed the emergency generators that would have provided power to cool the reactors. The insufficient cooling led to three nuclear meltdowns, hydrogen-air chemical explosions, and the release of radioactive material in Units 1, 2 and 3 from 12 March to 15 March. Loss of cooling also caused the pool for storing spent fuel from Reactor 4 to overheat on 15 March due to the decay heat from the fuel rods.

• Onagawa

- All safety systems functioned as designed, the reactors automatically shut down without damage, and no reactor damage occurred. Due to the earthquake, a fire broke out in the Turbine hall, which is sited separately from the plant's reactor, but was extinguished in a few hours.
- Following the tsunami two to three hundred homeless residents of the town who lost their homes to the tsunami took refuge in the Onagawa nuclear plant's gymnasium, as the reactor complex was the only safe area in the vicinity, with the reactor operators supplying food and blankets to the needy.

2017

- Fukushima Daiichi
  - Will never operate again
  - Will continue to contaminate the environment for up to 40 years
  - The loss of 30% of the country's generating capacity – All but two nuclear stations were shut down
  - "public confidence in safety of nuclear power was greatly damaged"
  - Have already spent $187 Billion plus $37 Billion per year (nationally) in replacement power costs

- Onagawa
- Restart requested in 2013 after thorough inspection and verification

Special Note

- One interesting story detail was the back-and-forth discussions at Onagawa design review meetings:
  - Mr. Hirai demanded a 49 ft sea wall height;
  - The committee wanted 30ft.
  - They agreed on 46ft.
- The 2011 tsunami reached 43ft at Onagawa (only a 3ft safety margin!!). Post-event they have raised the wall another 13 feet (to 56 feet).
- In contrast, TEPCO built Fukushima's sea wall to withstand less than a 19ft wave.

- Takeaways from this event include:
  - The importance of ongoing learning from internal and external events,
  - Why a "meeting minimum requirements" mindset is eventually disastrous, and
  - The importance of leadership in driving the right safety culture.

WRAP-UP

- The Fukushima Daiichi Nuclear Power Station's meltdowns were not due to the natural disaster, but rather to a series of decisions by Tepco not to be proactive with safety, dating back to when the reactors were being constructed. With most other factors being similar, it was Tokohu Electric's overall organizational practices and safety culture that saved the day for Onagawa. If safety and disaster response had been properly recognized, addressed, and implemented at Fukushima Daiichi—–as they were within Tohoku Electric's corporate safety culture—–perhaps the disastrous meltdowns would have been prevented.
  - The Bulletin.org

What does this mean for us?

- We handle hazardous materials on a daily basis
- It is necessary that we protect the Public, the Environment and our Employees from harm.
- Thus, from this example, we cannot accept "minimum requirements" without accepting the consequences
- Specifically related to our Leak Detection Programs, we need to ensure we're doing all we can to minimize releases.

References

- **Why You Haven't Heard About Onagawa Nuclear Power Station after the Earthquake and Tsunami of March 11, 2011;** Airi (Iris) Ryu1 & Najmedin Meshkati2 aryu@usc.edu & meshkati@usc.edu; Vitebi School of Engineering University of Southern California (USC); Adapted from a research term paper for Human Factors in Work Design (ISE 370L), Fall 2013 Daniel J. Epstein Department of Industrial & Systems Engineering, USC; Revised and updated February 26, 2014 (https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&cad=rja&uact=8&sqi=2&ved=0ahUKEwiBq-zd_IrTAhUk0IMKHbvqBLgQFgg2MAM&url=http%3A%2F%2Fwww-bcf.usc.edu%2F~meshkati%2FOnagawa%2520NPS-%2520Final%252003-10-13.pdf&usg=AFQjCNEPRHmFnvuwVEe3oPx3f81M4d342w&sig2=YRS-RkEpMMcCfXKq_0YnqQ&bvm=bv.151426398,d.amc)
- https://en.wikipedia.org/wiki/Fukushima_Daiichi_nuclear_disaster
- https://en.wikipedia.org/wiki/Onagawa_Nuclear_Power_Plant
- DNV GL – Chris Boylan, Risk Advisory Services, Oil and Gas; Chris.Boylan@DNVGL.com

Risk Management and Selection of Leak Detection Methods and Technologies

Phil Martin

Supervisor Leak Detection CPM Maintenance

Enbridge

Agenda

- Speaker Introduction
- Spill Risk Metrics and Management in an API 1175 LDP Context
- Magellan's Process of Improving Integration with Leak Detection and their Integrity Management Plan
- Leak Detection Technology Selection using a Risk-Based Approach
- Questions

Author Bio – Philip Carpenter

- 40 years of engineering experience, 35 of which have been spent working in the pipeline industry as hydraulics engineer, discipline engineering supervisor, manager, and independent consultant. His current areas of focus are steady state and transient pipeline hydraulics, pipeline operation and control, real time systems, statistical analysis, pipeline leak detection, risk analysis, and computer application development with an emphasis on numerical simulation of physical processes. His company, Great Sky River Enterprises, LLC, provides services in these areas to the oil and gas industry.
- Philip has a B.Sc. in Aerospace Engineering and an M.S. in Engineering Science.

AUTHOR BIO – ROBERT CRAIG

- Robert Craig has worked within Magellan and its predecessor for 28 years. He has been active in API Cybernetics for the last decade, participating in several initiatives and RPs. For the last 18 years he has been in Magellan's Control Room in SCADA, CPM Leak Detection, Controller Training, Equipment Maintenance, Alarm Management, and Control Room Management Compliance.
- Robert has a B.Sc. in Computer Science from ORU. He and his wife have lived in Tulsa, Oklahoma for 33 years.

AUTHOR BIO – NIKOS SALMATANIS

- Nikos has been with Chevron from 2002 and has prior work experience in Software Development, Refinery, Petro-Chemical Plans, Cybersecurity, and Environmental Research
- He is a specialist in the application of pipeline leak detection and has conducted 100+ Leak Detection Capability Evaluations
- He is also an active member with API, AOPL, ASTM, PRCI
- Nikos has a B.Sc. in Chemical Engineering from the University of Houston

PRESENTATIONS START

QUESTIONS

API RP 1175
PIPELINE LEAK DETECTION-PROGRAM MANAGEMENT WORKSHOP

Spill Risk Management in an API 1175 Context

Morgan Henrie   Philip Carpenter Ed Nicholas

WEDNESDAY AND THURSDAY, APRIL 26TH AND 27TH, 2017

"I OFTEN SAY THAT WHEN YOU CAN MEASURE WHAT YOU ARE SPEAKING ABOUT, AND EXPRESS IT IN NUMBERS, YOU KNOW SOMETHING ABOUT IT; BUT WHEN YOU CANNOT MEASURE IT, WHEN YOU CANNOT EXPRESS IT IN NUMBERS, YOUR KNOWLEDGE IS OF A MEAGRE AND UNSATISFACTORY KIND; IT MAY BE THE BEGINNING OF KNOWLEDGE, BUT YOU HAVE SCARCELY, IN YOUR THOUGHTS, ADVANCED TO THE STAGE OF *SCIENCE*, WHATEVER THE MATTER MAY BE."

- William Thomson, 1st Baron Kelvin, 1824 - 1907
  - Lecture on "Electrical Units of Measurement" (3 May 1883)

Theme for this Talk

- **Optimizing the ability to quickly detect leaks is a complex task**
  - **API 1175 provides a mechanism to manage this process**
  - **Addresses integration of leak detection systems, performance testing, operator training, alarm management, field surveillance, and many other components via a *Leak Detection Program***
- **But leak detection is only one aspect of spill risk management**
- **Some questions you should ask when developing your LDP:**
  - **Just what is the best set of leak detection approaches for my pipeline?**
  - **What actual benefit is provided by my leak detection program?**
  - **How can I measure that benefit?**
  - **If my budget for pipeline spill risk management is constrained…then just how much should I spend on leak detection?**
  - **How do I fit my LDP into a larger *Spill Risk Management Program*?**

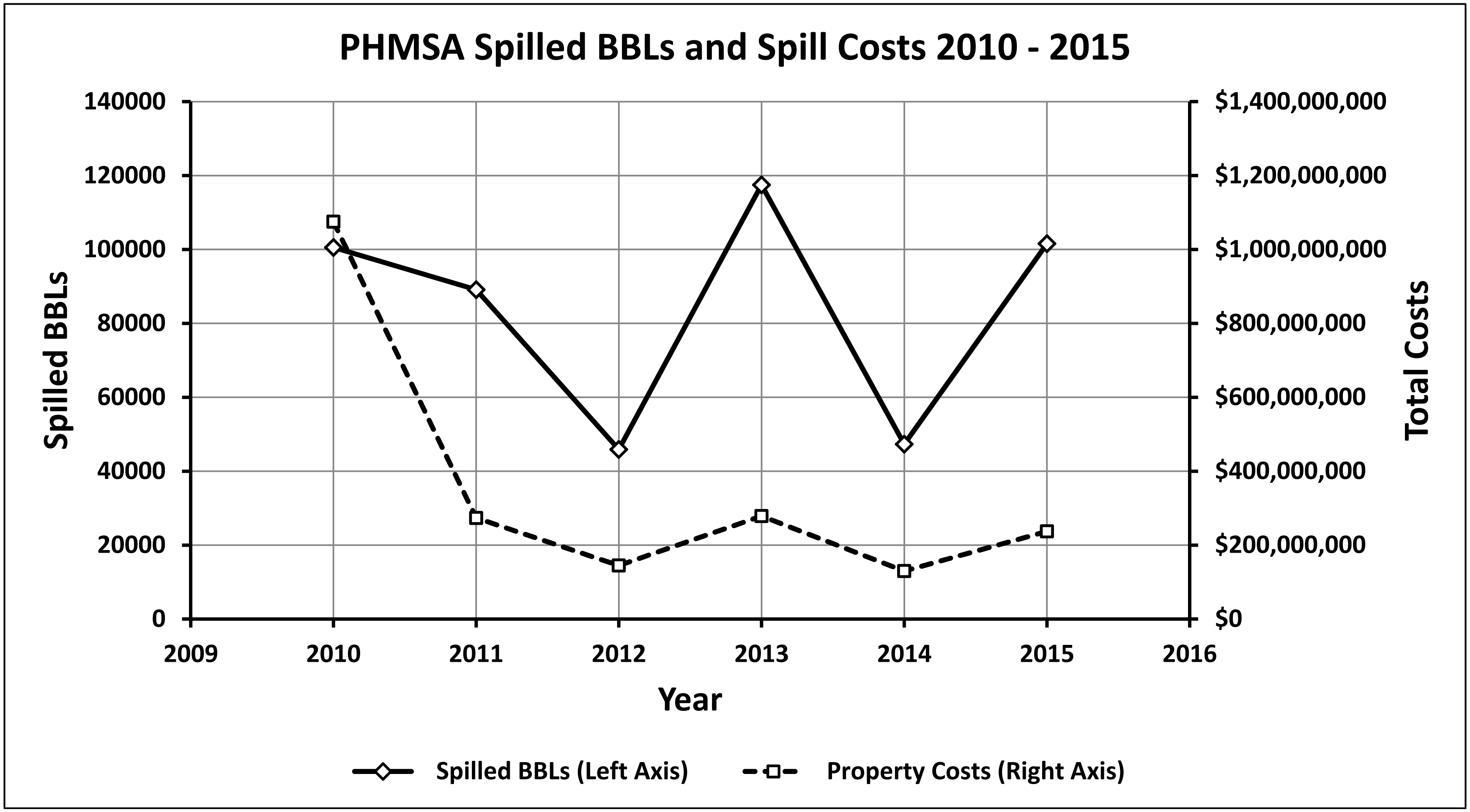
Presentation Overview

- Review of PHMSA liquid pipeline data
  - How much do pipeline spills cost?
  - And how are they detected?
- Understanding CPM System performance at a high level
- Using LDS performance testing to understand the limits of your own system
- Analyzing spill volume for different leak detection approaches
  - How much can your LDP affect total spill volume?
- Relating spill volume to spill cost
- Integrating the LDP into a comprehensive spill risk management program

PHMSA DATA ANALYSIS

- High-level results based on DOT PHMSA spill database 2010 – 2015
- Goal was to understand:
  - Spill frequency
  - How spills are distributed by size
  - How much they cost
  - Which methods appear to be most effective at detecting them

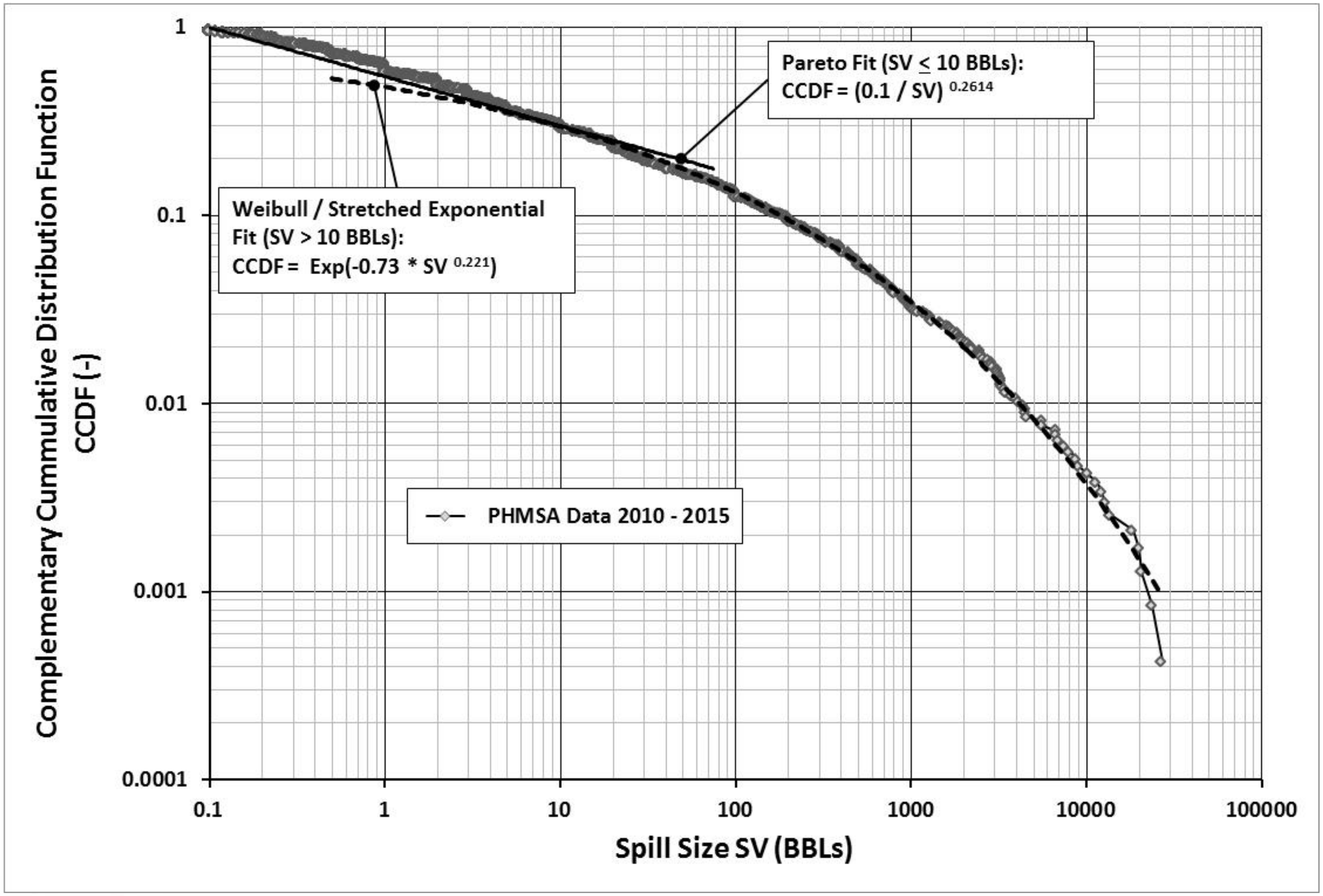
Spill Volumes and Costs over Time



PHMSA Data Overview Take-Aways

- Spill volumes are highly-variable year-to-year
- Costs can be highly disproportionate to volumes
  - High costs in 2010 were based on one high volume spill with disproportionately high per-barrel costs
- The system-level spill incident rate is surprisingly constant at about 0.002 incidents/mile/year
  - Individual pipeline rates are likely to vary from this considerably (i.e., your mileage may vary)

Spill Size Distribution

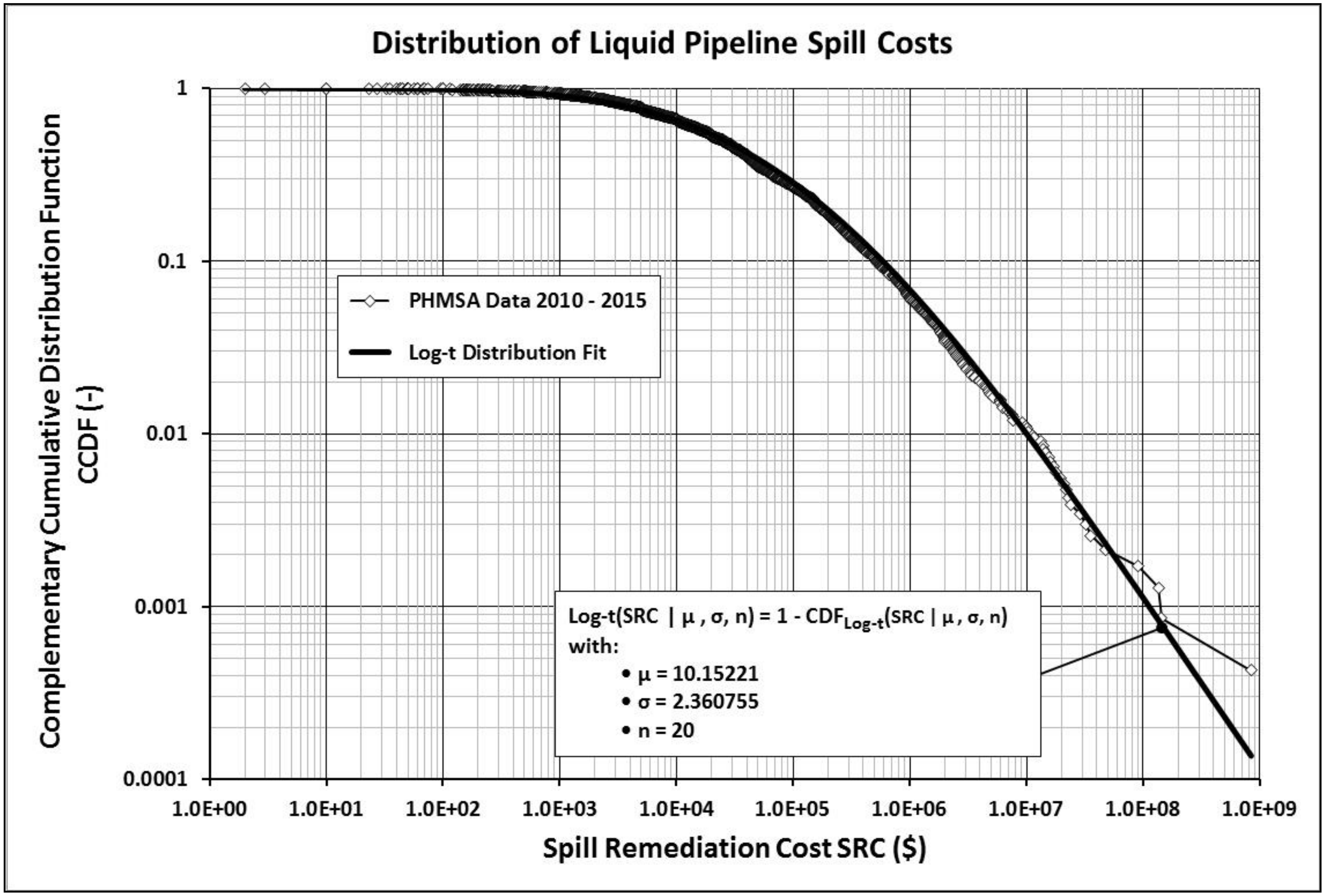


SPILL SIZE DISTRIBUTION TAKE-AWAYS

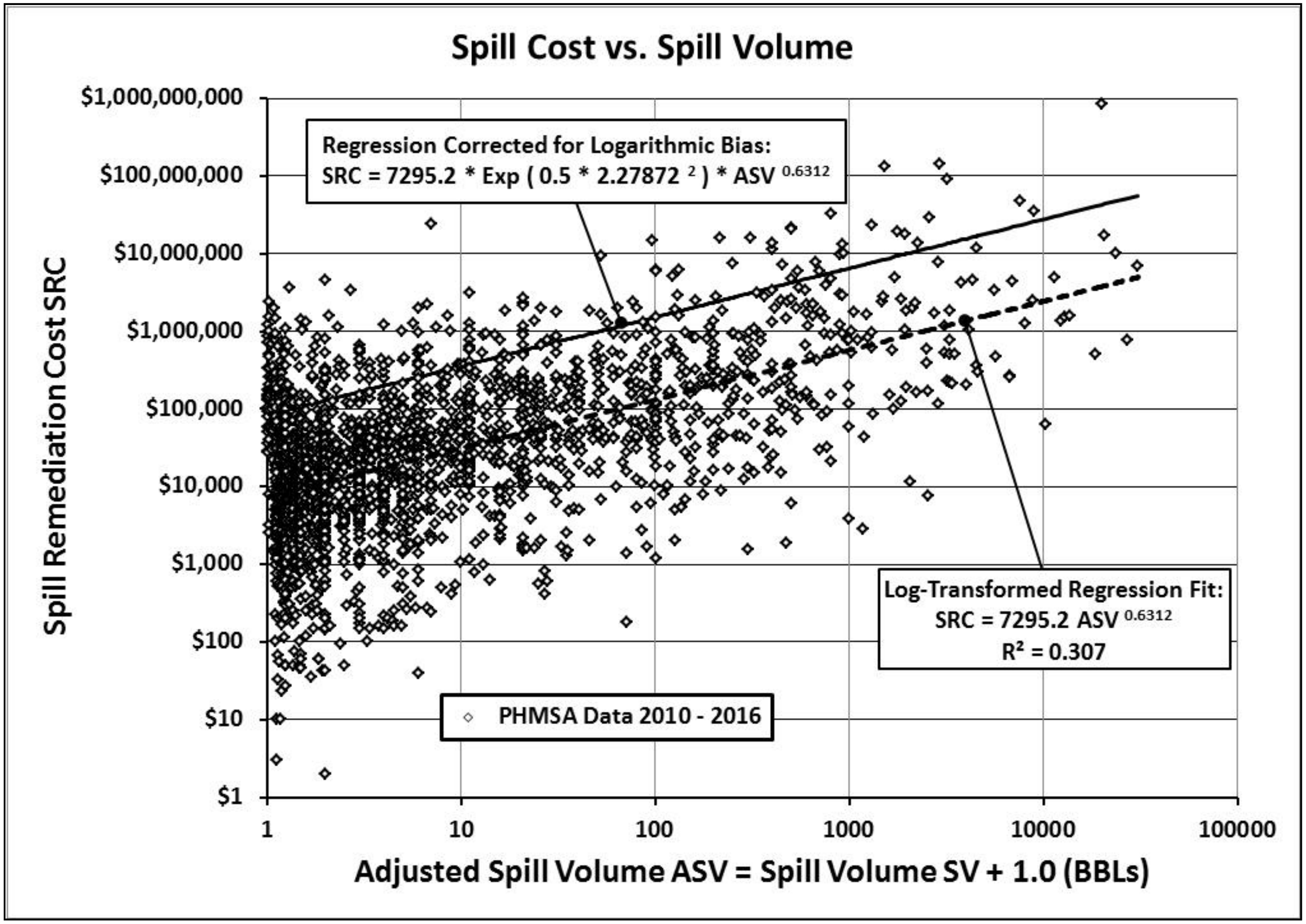
- **The median spill volume is 2 BBLs**
  - **70% of all spills are less than 10 BBLs in size**
  - **40% are less than 1 BBL**
- **Large spills greater than 1,000 BBLs constitute only about 3% of all spills.**
- **Monster spills greater than 10,000 BBLs constitute less than 0.4% of all events.**
  - **However, based on the current incident rate in the United States (~400 spills/year), we can expect 1 to 2 such incidents every year.**

energy API

SPILL COST DISTRIBUTION



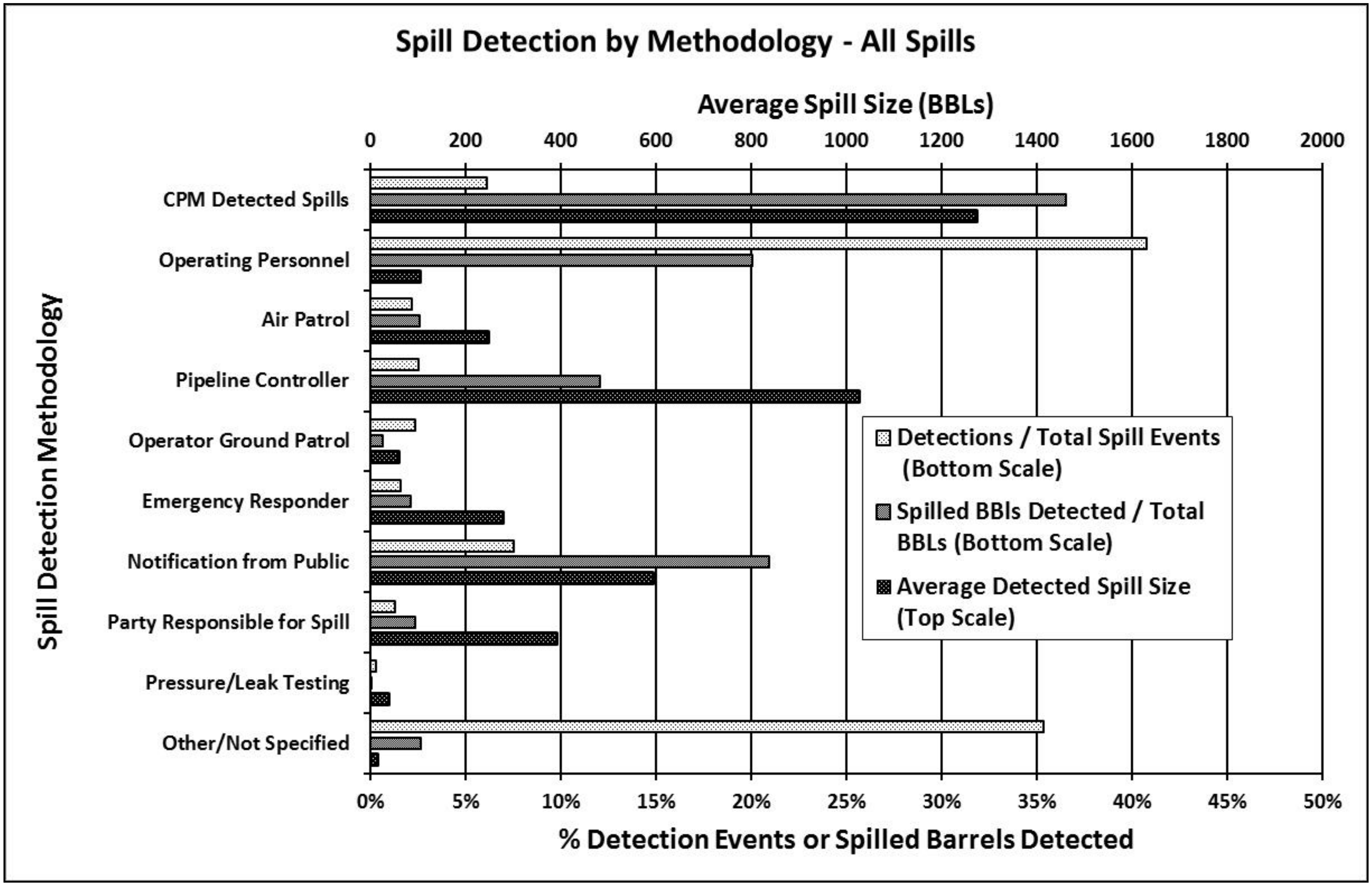
SPILL COST VS SPILL VOLUME



Spill Cost Distribution Take-Aways

- **The *median* spill incident/remediation cost is $10,000**
- **However, the *average* spill costs about $900,000**
  - **Even small leaks of about 1 BBL in size cost (on average) about $100,000**
- **There is a real correlation between spill volume and cost**
  - **The correlation is significant**
  - **Nonlinear and slower than linear**
  - **Coefficient of determination: $R^2 \sim 0.3$**
- **This means that the remaining 70% of the total cost variance is**
  - **Situational**
  - ***Not* a function of spill volume**

Spill Detection by Methodology - All Spills



SPILL DETECTION METHODOLOGY TAKE-AWAYS

- **PHMSA data indicate that *at least* 58% of leaks are detected at the spill site through direct observation**
  - **Operating company personnel**
  - **The general public detect a surprisingly large fraction of spills**
- **CPM Systems are responsible for about 6% of all detections**
  - **This figure rises to 9% on pipeline rights-of-way**
  - **PHMSA statistics indicate that only ~31% of pipelines have CPM**
  - **If true, this would probably increase our CPM detection rates accordingly**
  - **This kicks up our CPM incident detection rate up to ~ 15-30%?**
  - **Not trivial…but it still seems kind of low**

More Spill Detection Method Take-Aways

- Spill volumes for CPM detection also tend to be on the high side
  - CPM detects 36% of all spilled volumes
  - 47% of volumes on rights of way
  - Why are these numbers so large?
- Pipeline controllers (remote from the spill site) are responsible for spotting 3 – 4 % of spills
- No detection method was supplied by operators for 35% of all PHMSA-reported spills

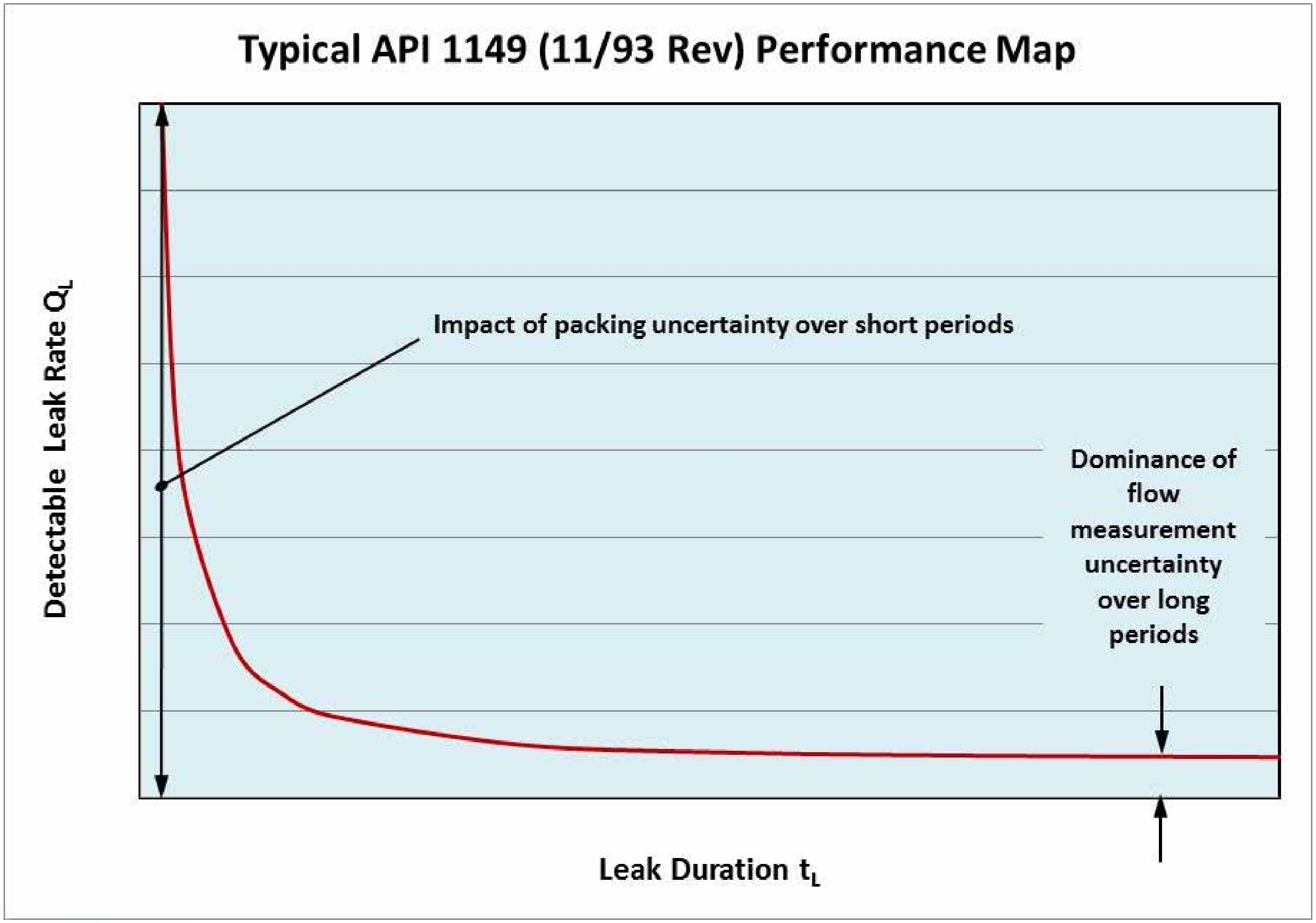
CPM SYSTEM PERFORMANCE FUNDAMENTALS

- **It's hard to understand some of these results without taking a look at some leak detection fundamentals**
- **CPM Performance Equation (API 1149/November 1993):**

$$\frac{Q_L}{Q_{Ref}} = \sqrt{\Delta k_{in}^2 + \Delta k_{out}^2 + \left(\frac{\Delta V_{PK}}{t_L Q_{Ref}}\right)^2}$$

  - Δk_{IN} **and** Δk_{OUT} **are flow meter uncertainty factors for a pipeline segment**
  - ΔV_{PK} **is the pipeline segment packing uncertainty**
  - Q_L **is the leak flow**
  - Q_{Ref} **is the pipeline design flow**
  - t_L **is the time or period that the pipeline has been in a leak state**

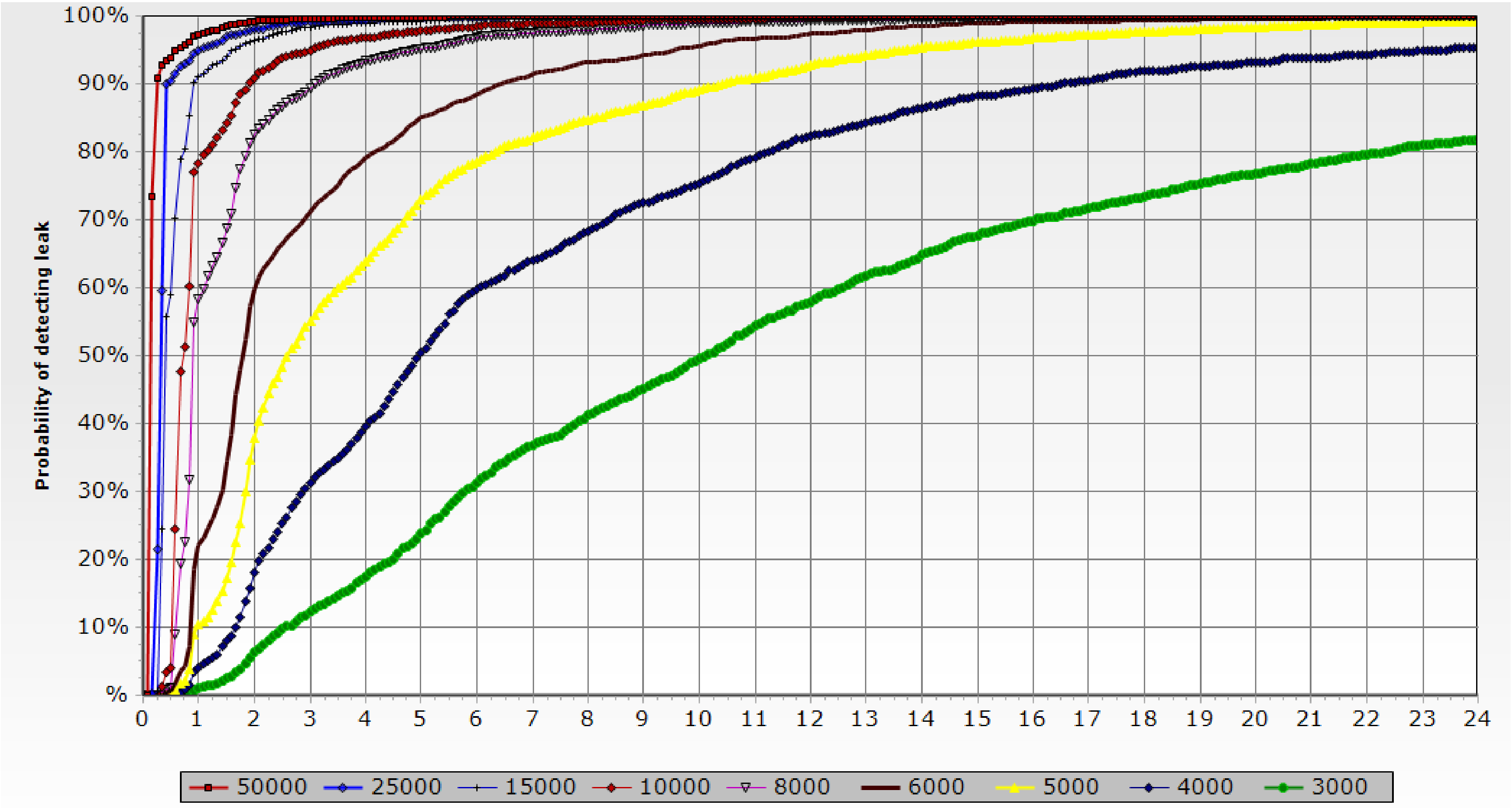
TYPICAL CPM LEAK DETECTION SENSITIVITY MAP



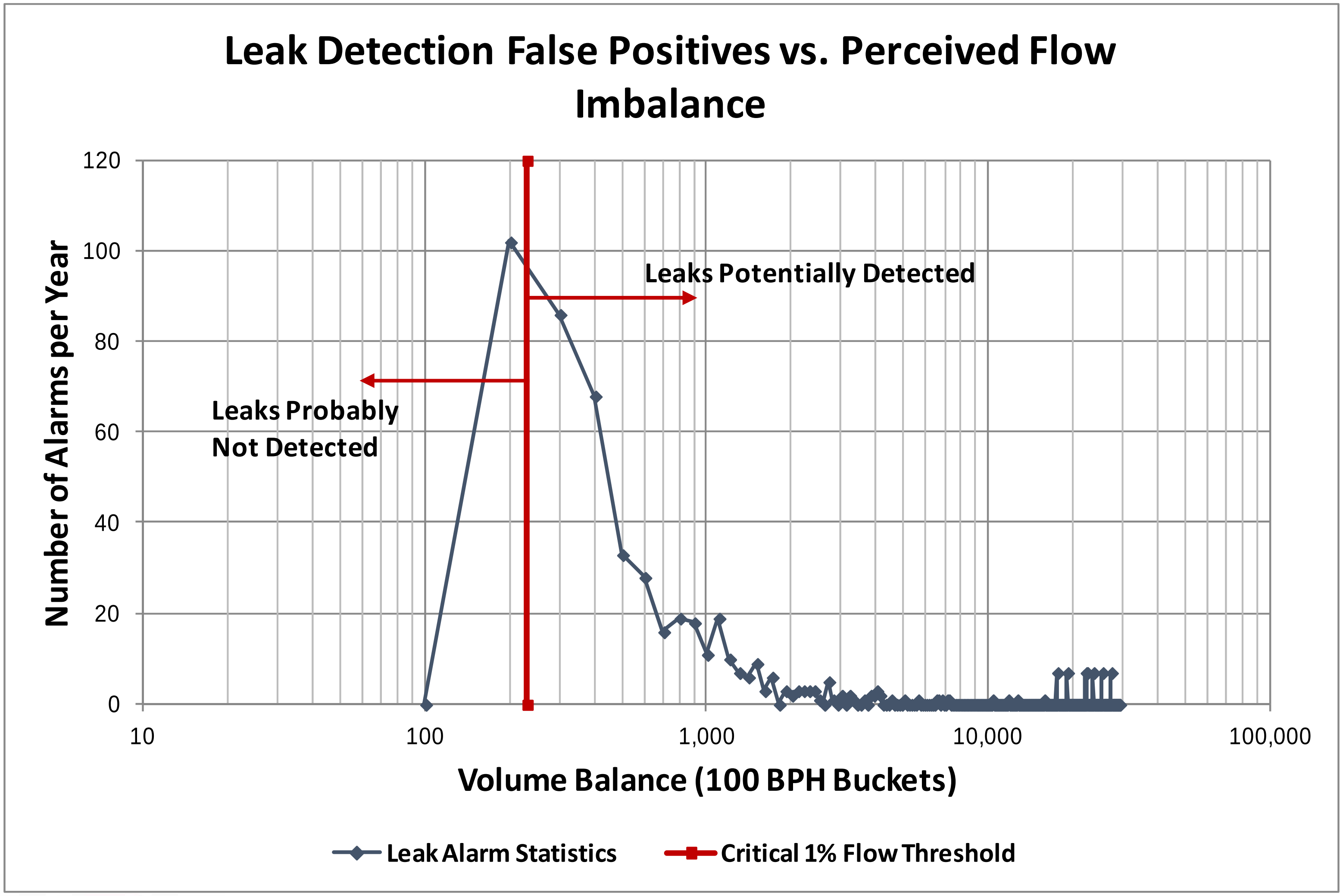
LDS PERFORMANCE TESTING

- **API 1130 Section 6.2 and API 1175 Section 5 both require that CPM systems be periodically tested to establish performance**
  - **Commodity withdrawal**
  - **Software simulations**
  - **Instrument edits**
- **Most existing methods confirm functionality with little detail**
- **The most comprehensive and detailed results are obtained by imposing leak perturbations on recorded SCADA data, running the data stream through the LDS, and developing performance maps**
  - "Accurately Representing Leak Detection Capability and Determining Risk," Philip Carpenter, Ed Nicholas, Morgan Henrie, PSIG 2005
  - "A New Approach To Testing the Performance of a Pipeline Leak Detection System," Ed Nicholas, Philip Carpenter, Morgan Henrie, Daniel Hung, Kris Kundert PSIG 2017

LDS TESTED SENSITIVITY MAP



LDS Tested False Positives



LDS TESTING TAKE-AWAYS

- CPM and other leak detection systems are subject to fundamental limitations in terms of their ability to detect a leak in progress
- It is nearly impossible to understand these limits if you don't test the system
- In-place testing during operation is very unlikely to provide sufficient detail to understand these limits
- Offline methods that impose leaks on recorded data can provide the desired information

Spill Volumes Detected by CPM

- **The previous discussions have revolved around relating leak detection performance to spill rate**
- **But spill costs are a function of spill *volume, not* a function of spill rate!**
- **Returning to our CPM Performance Equation (API 1149/November 1993):**

$$\frac{Q_L}{Q_{Ref}} = \sqrt{k_{in}^2 + k_{out}^2 + \left(\frac{\Delta V_{PK}}{t_L Q_{Ref}}\right)^2}$$

- **And remembering that spill volume is $V_S = t_L Q_L$,**
- **We can invert this to obtain the spill volume at time of detection:**

$$V_S = \frac{\Delta V_{PK}}{\sqrt{1 - 2k_{i,o}^2 \left({Q_{Ref}}/{Q_L}\right)^2}}$$

SPILL VOLUMES DETECTED BY SITE OBSERVATION

- **What about spills that are detected by people?**
- **Let's assume that the spill site is visited with some sampling period t_S**
  - **The interval between site visits**
- **We'll also assume that there is an initial amount of *occulted* oil V_O that cannot be observed:**
  - **Primarily because it's still in the ground and has to work its way to the surface**

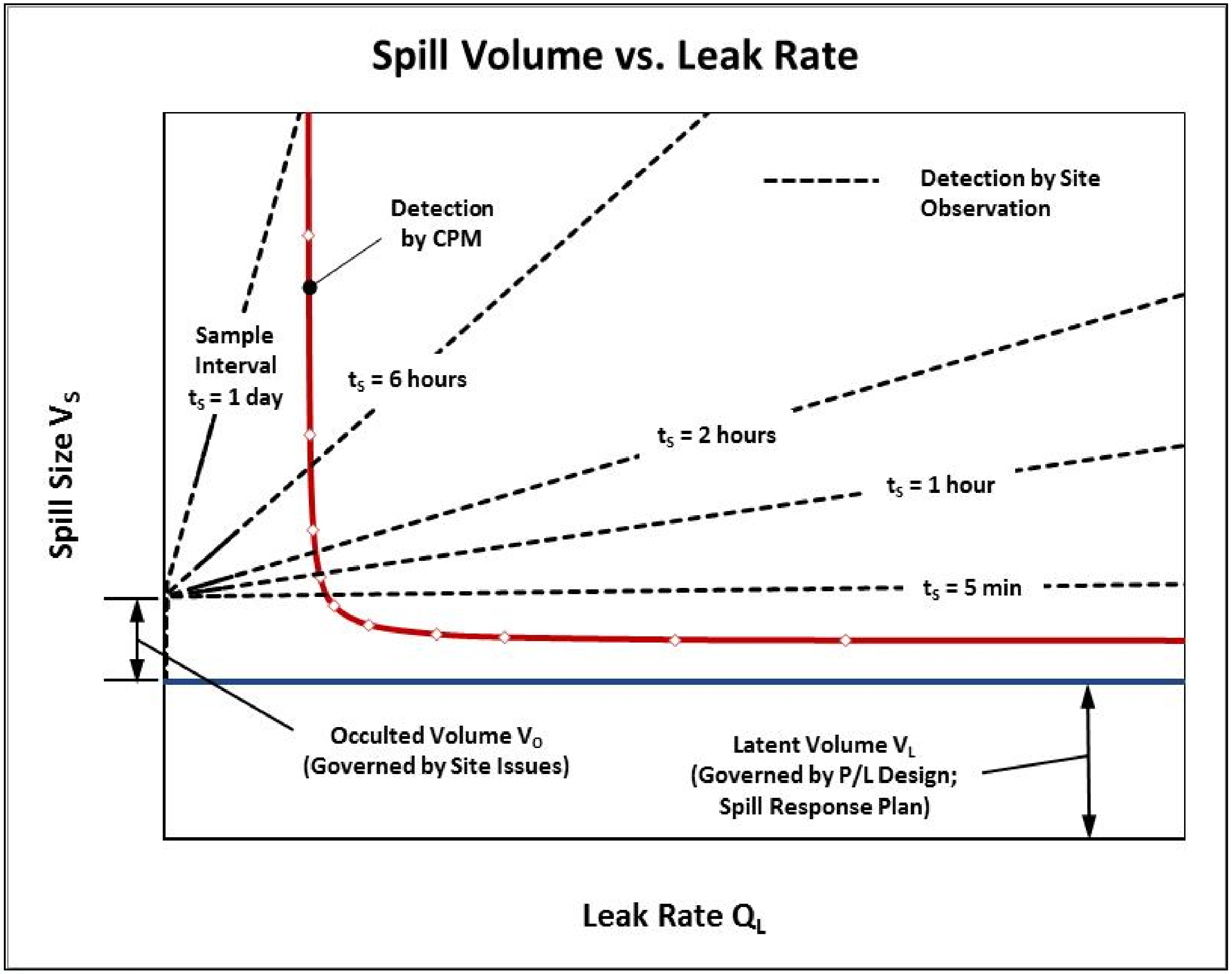
$$V_S = V_O + t_S Q_L$$

  - **The occulted oil can be huge if the oil drains to a culvert or other location where it moves away from the spill site and is only detected with some considerable delay**

ADDITIONAL SPILL VOLUMES

- **Occulted spill volumes are not subject to reduction as a result of faster leak detection**
- ***Latent* volume V_L is volume that continues to accumulate *after* the leak is detected and the pipeline shut down**
  - **Continued drainage while the pipeline is shutdown and the line is isolated**
  - **Drainage through the leak hole between remote isolation valves**
  - **Drainage from the leak site between temporary stopples and other emergency isolation devices**
- **The latent volume is a function of the leak location, the pipeline design, and the Spill Response Plan**
  - **It generally cannot be reduced by improvements to leak detection**

ALL SPILL VOLUMES



SPILL VOLUME ANALYSIS TAKE-AWAYS

- Direct observation and CPM Systems comprise the two largest mechanisms for detection for pipeline spills
- Both work
- Neither approach by itself can efficiently cover the complete range of expected leak conditions
- Some spill volumes cannot be reduced by improving leak detection alone

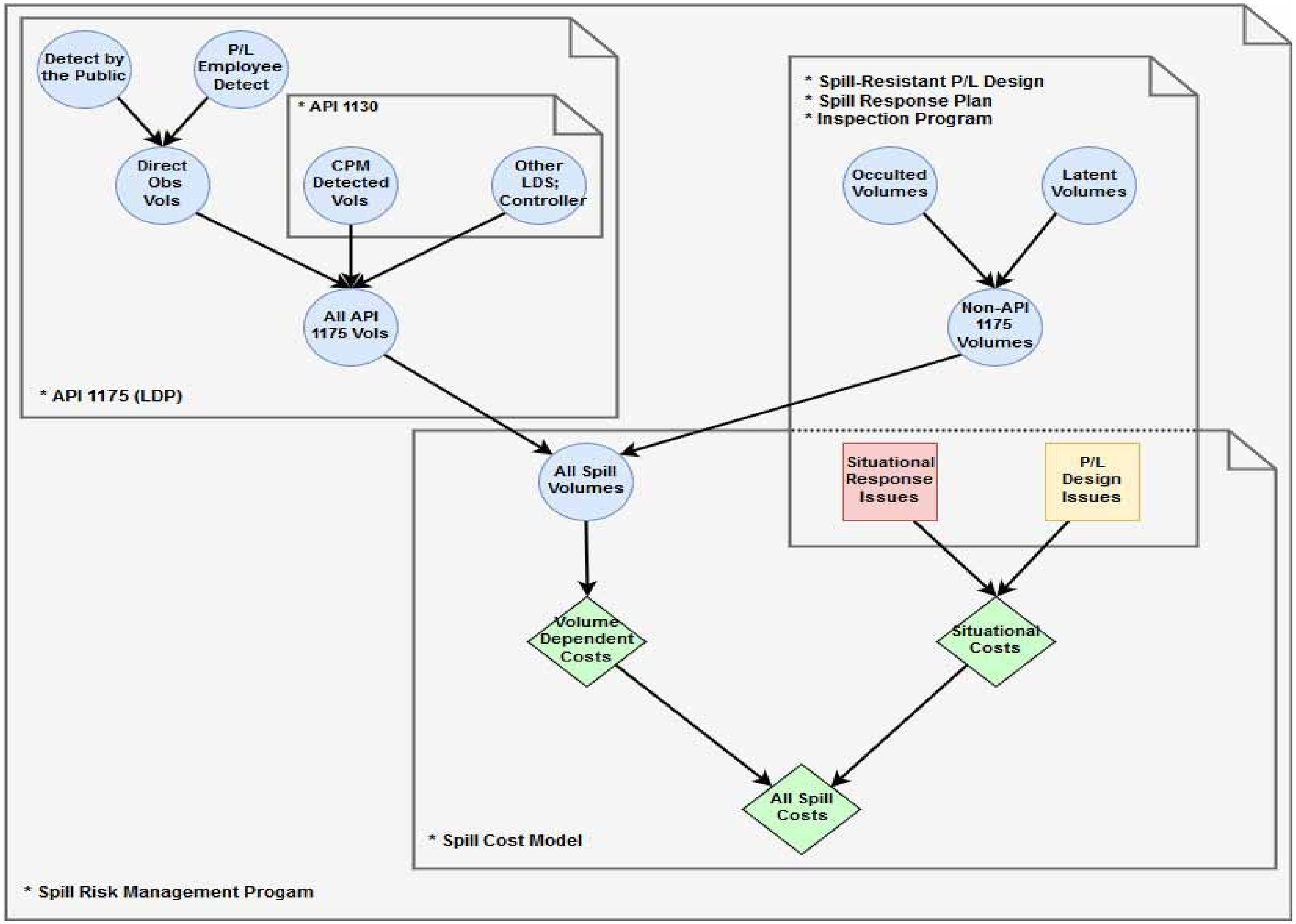
Spill Risk/Cost Take-Aways

- We've previously seen that spill costs are a function of:
  - Total spill volume
  - Situational issues
  - Shutdown/out-of-service costs?
- As noted previously, situational costs may be a larger component of total spill costs than the volume-related costs
  - Discharge into HCA, wetland, river crossing, reservoir, etc.
  - Poorly implemented operator spill response
  - Large number of injured parties
  - Personal injury or death
- Situational variation can increase or reduce total costs
  - Depends on your spill cost model (assuming you have one...)

CONCLUSIONS

- CPM Systems and Direct Observation methodologies are individually inadequate to minimize the volume of commodity spilled
  - CPM Systems (or leak detection equivalents) excel for high leak rate spills but perform poorly or are totally inadequate at low leak rates
  - Direct observation mechanisms perform well for the large number of incidents at low leak rates, but perform poorly for rarer, high leak rate spills
- It is difficult to minimize the detected spill volume if you can't quantify the performance of your leak detection systems:
  - Testing and/or analysis
- Faster/better leak detection reduces only one aspect of spill volumes
  - Improving your LDP will not affect occulted and latent volumes
- Spill volumes ≠ spill costs!
  - Spill volumes are only one contributor to spill costs
  - Situational costs are at least as important and are not a function of the amount of commodity on the ground

SPILL MANAGEMENT COMPONENTS



The Bottom Line

- Integrating leak detection methodologies (particularly CPM and direct observation) needs to be a major component of any API 1175 LDP
- Quantify your LDS performance through testing and analysis if you want to optimize the blend of approaches and understand your worst case spill volume
- The LDP itself should integrate with other operating company programs and quantifiable tools to minimize total spill impact:
  - Spill cost model
  - Pipeline design that is robust in the face of leak/spill risk
  - Inspection program
  - Spill response plan
  - Spill risk management program

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