

# Diagnostic Testing of Stochastic Circuits

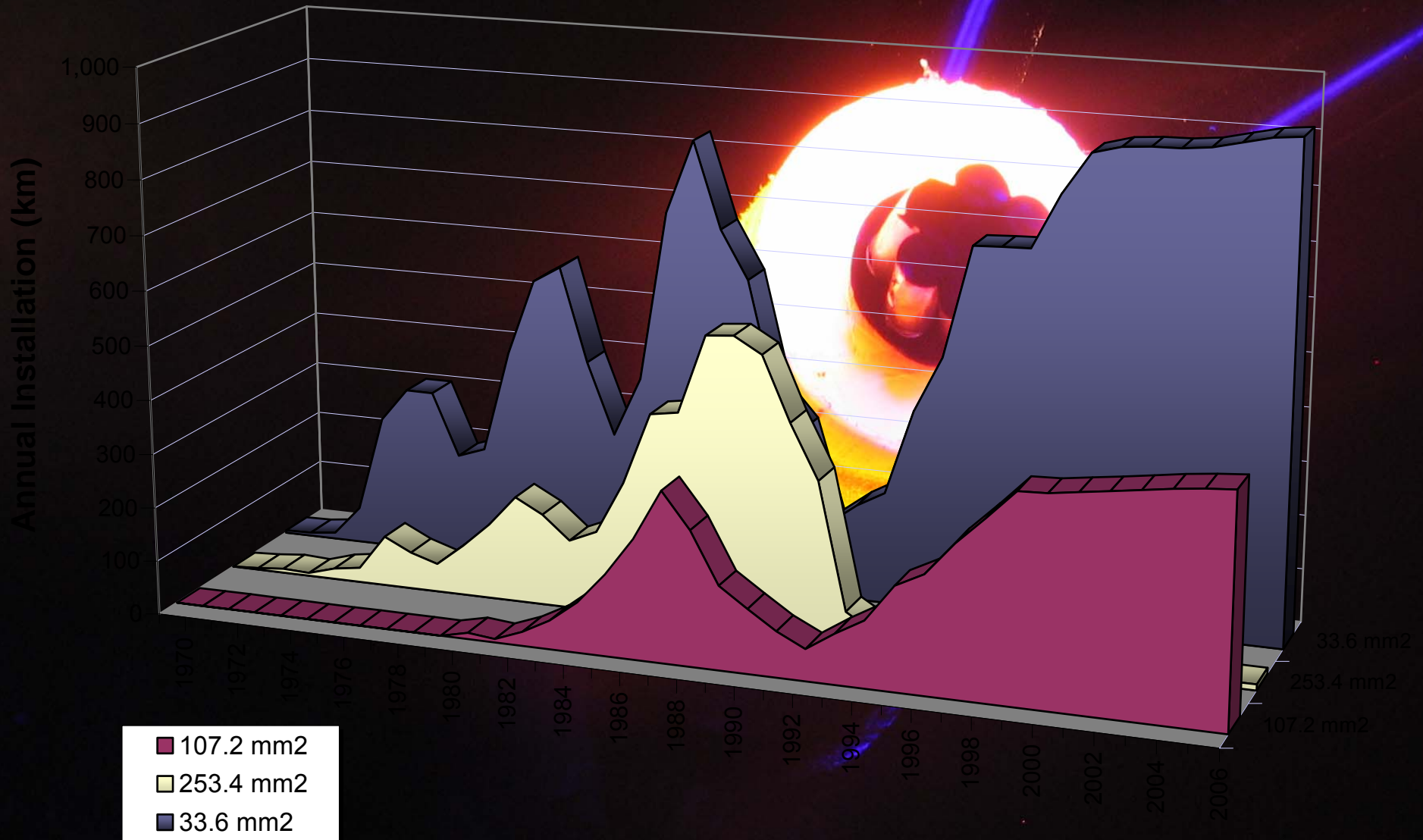


*ICC*

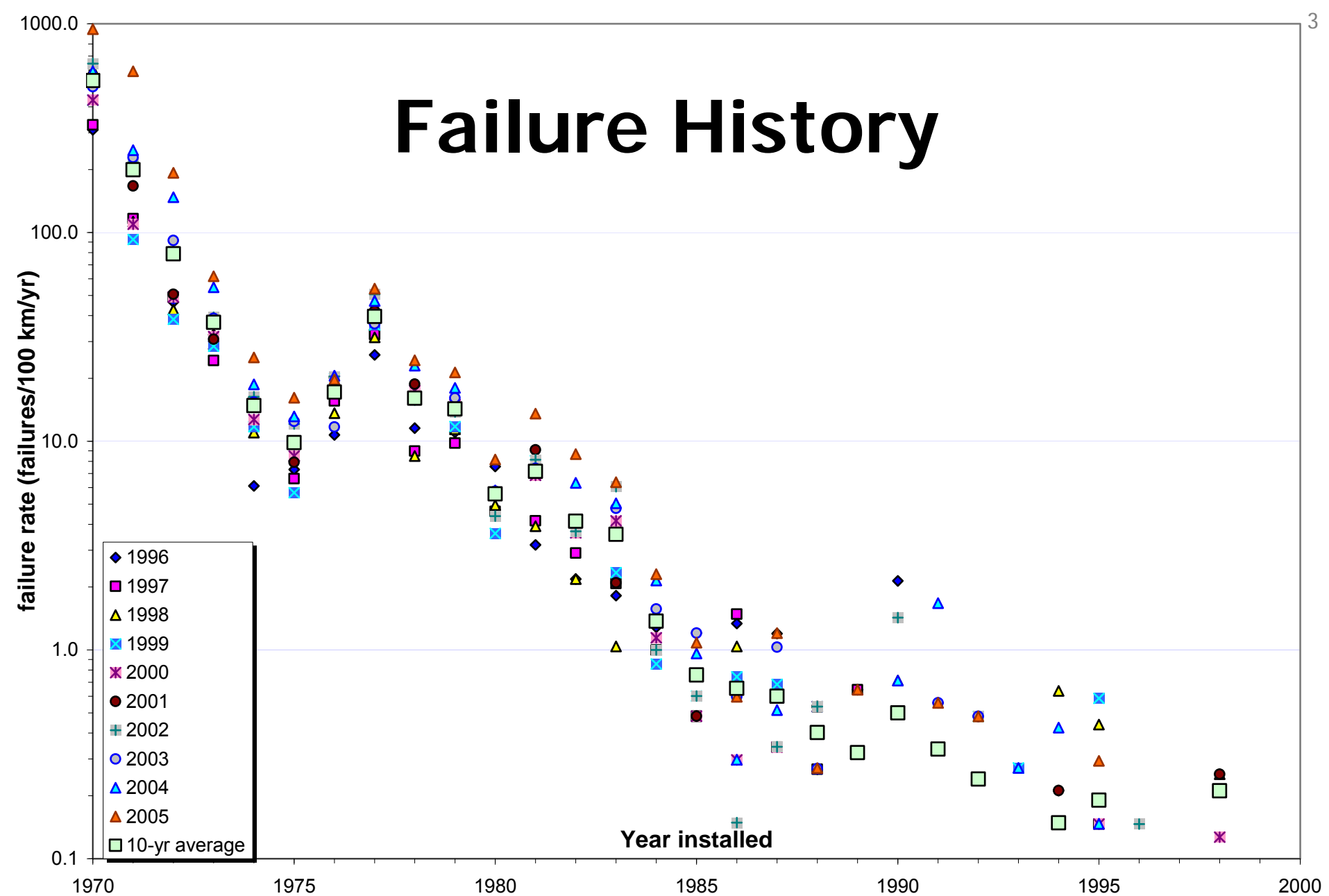
*November 6, 2007*

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# Installation History



# Failure History



**Diagnostic Goal:** Separate “good” from “bad”

**Consider:** “good”, “bad”, & “ugly” – 2 perspectives

## circuit owner

- Good: Fewer than X failures per length over next Y years
- Bad: Any cable that is not good.
- Ugly: “good” cable that fails (false negative); testing induced failures (false positive); reduced life

## diagnostic firm

- Good: No detectable incipient failures
- Bad: Cable damaged by diagnostic or incipient failure is detectable
- Ugly: False negatives ... cables which tested good, but fail within Y years of testing

# Incipient Failure

- Merriam-Webster: “beginning to come into being or to become apparent”
- Before defect becomes incipient failure, it must be a “pre-incipient failure” (generally a large water tree)
- Defect specific testing cannot find pre-incipient faults unless the test damages the cable
- 2nd law of thermodynamics assures: pre-incipient faults will convert to incipient faults over time

# Exemplary Cable Installation and Suspension Data (km)

27% of the of the '75 vintage population replaced from 2001-05.

Vintage:		1975	1976	1977
Installed		423.0	205.0	216.0
Suspended	2001	32.2	2.1	0.0
	2002	19.4	2.8	2.5
	2003	26.2	4.1	2.7
	2004	11.0	2.1	0.4
	2005	25.1	2.1	0.2

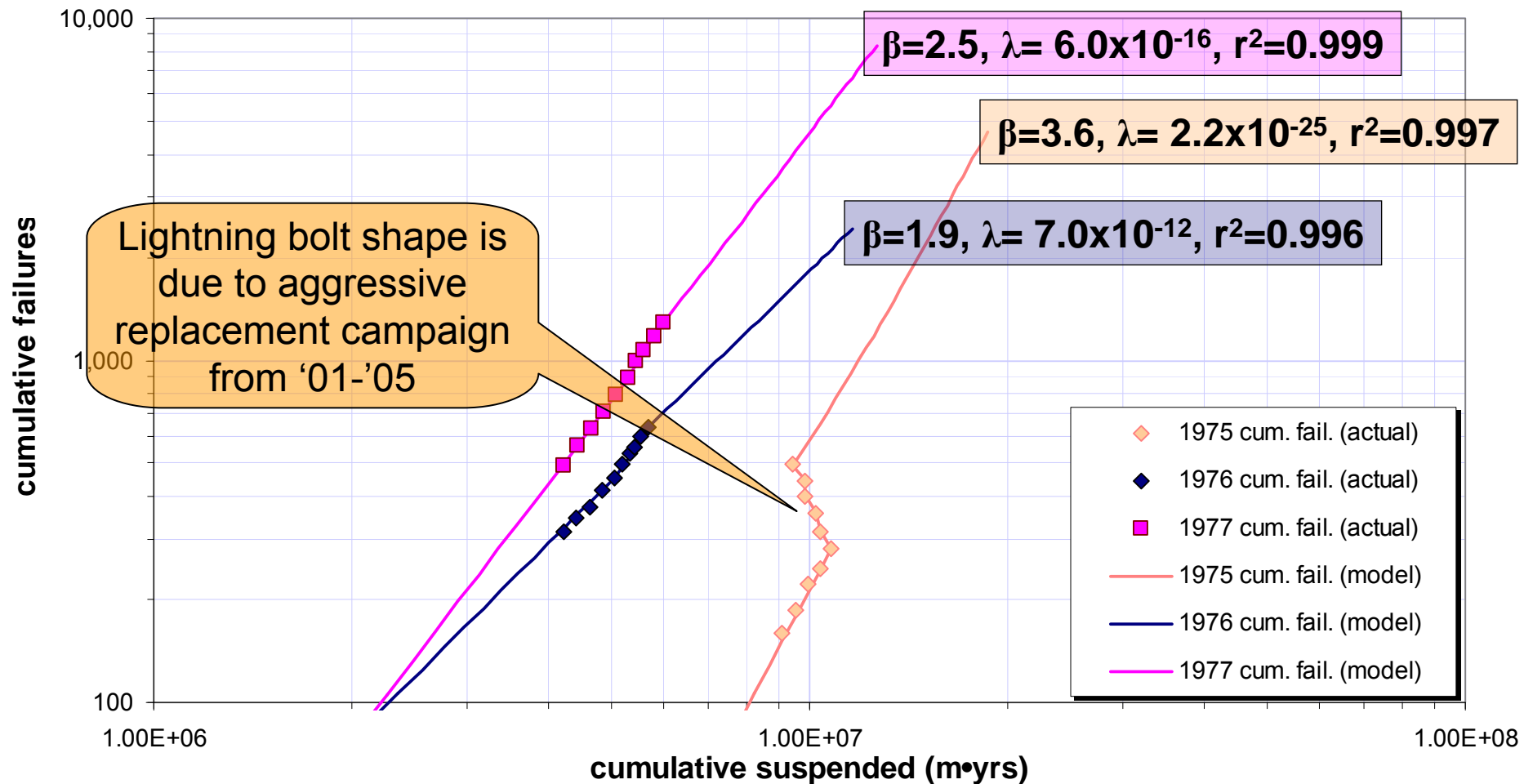
# Decade of Calendar year Failures

<b>Vintage:</b>	<b>1975</b>	<b>1976</b>	<b>1977</b>
1996	56	22	31
1997	70	32	28
1998	68	28	36
1999	78	41	24
2000	87	40	36
2001	91	41	31
2002	108	41	45
2003	77	23	43
2004	99	40	44
2005	113	38	50

# Crow-AMSAA: $N(t) = \lambda t^\beta$

- C-A is a power curve
  - cumulative failures versus
  - cumulative time • length
- $\beta$  provides insight ...
  - failures are increasing ( $\beta > 1$ ),
  - decreasing ( $\beta < 1$ ), or
  - remaining static ( $\beta = 1$ )
- Works well ...
  - For mixed mode failures
  - When missing data on early failures

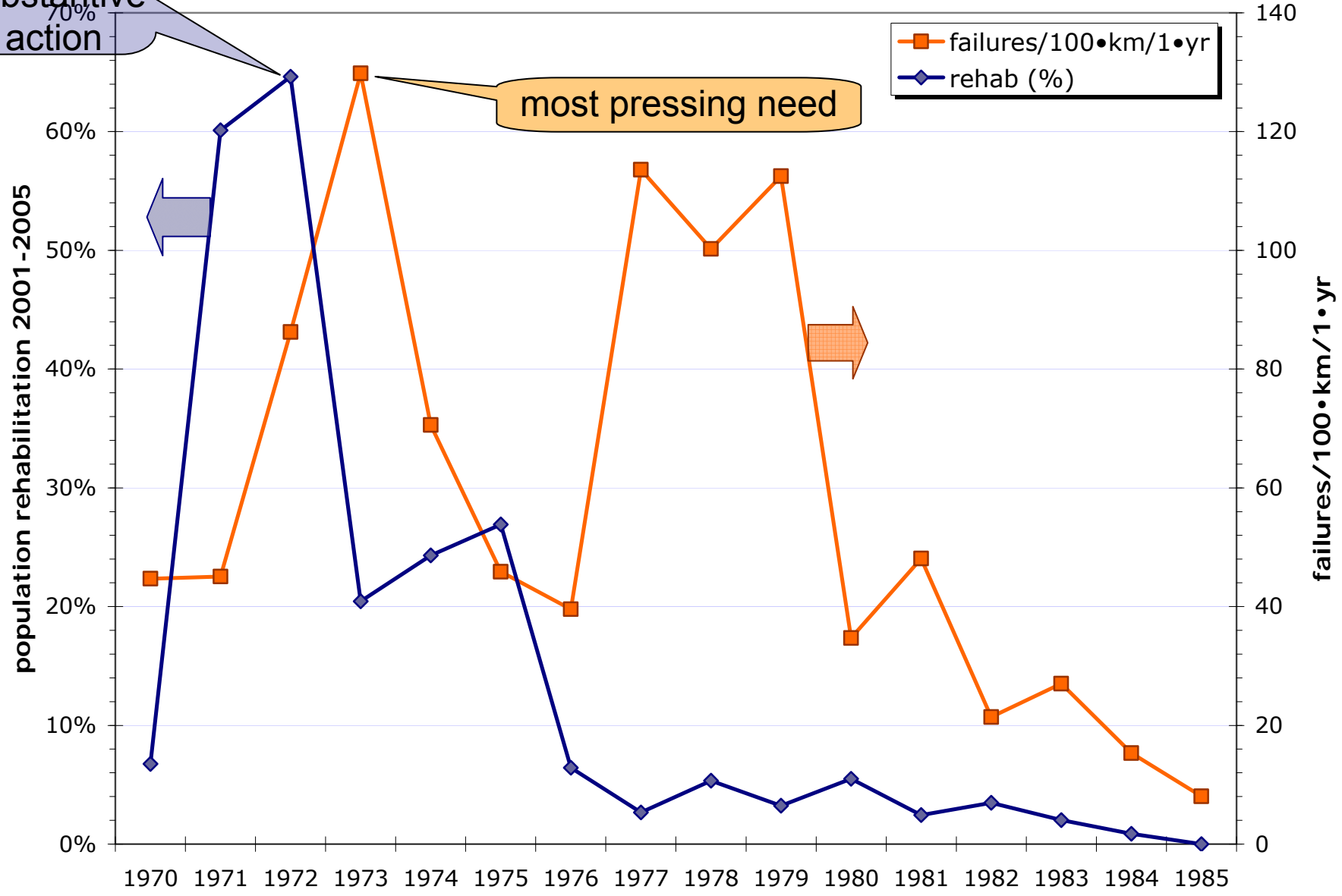
# Least Squares



# Concordance: Needs & Actions

most substantive action

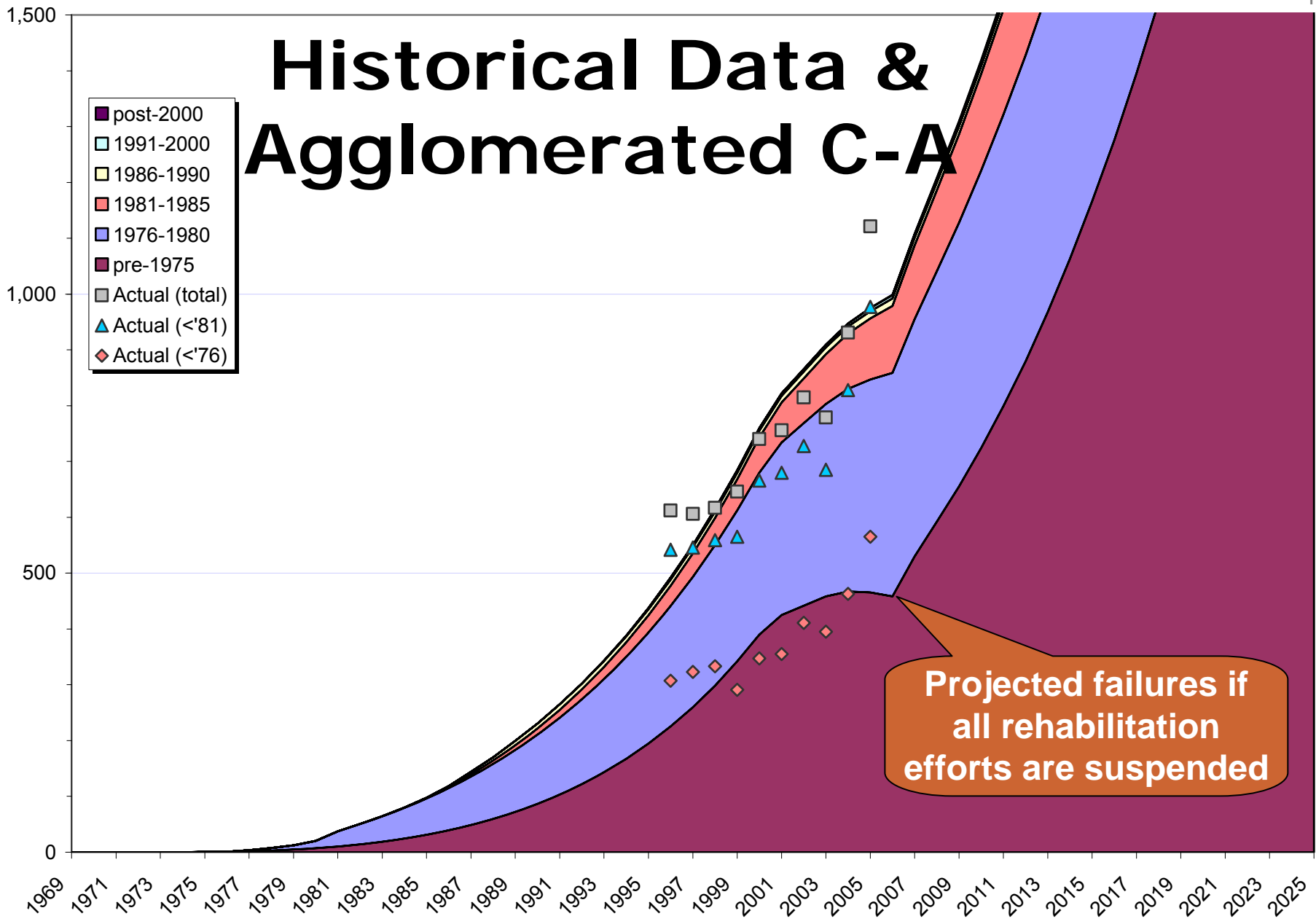
most pressing need



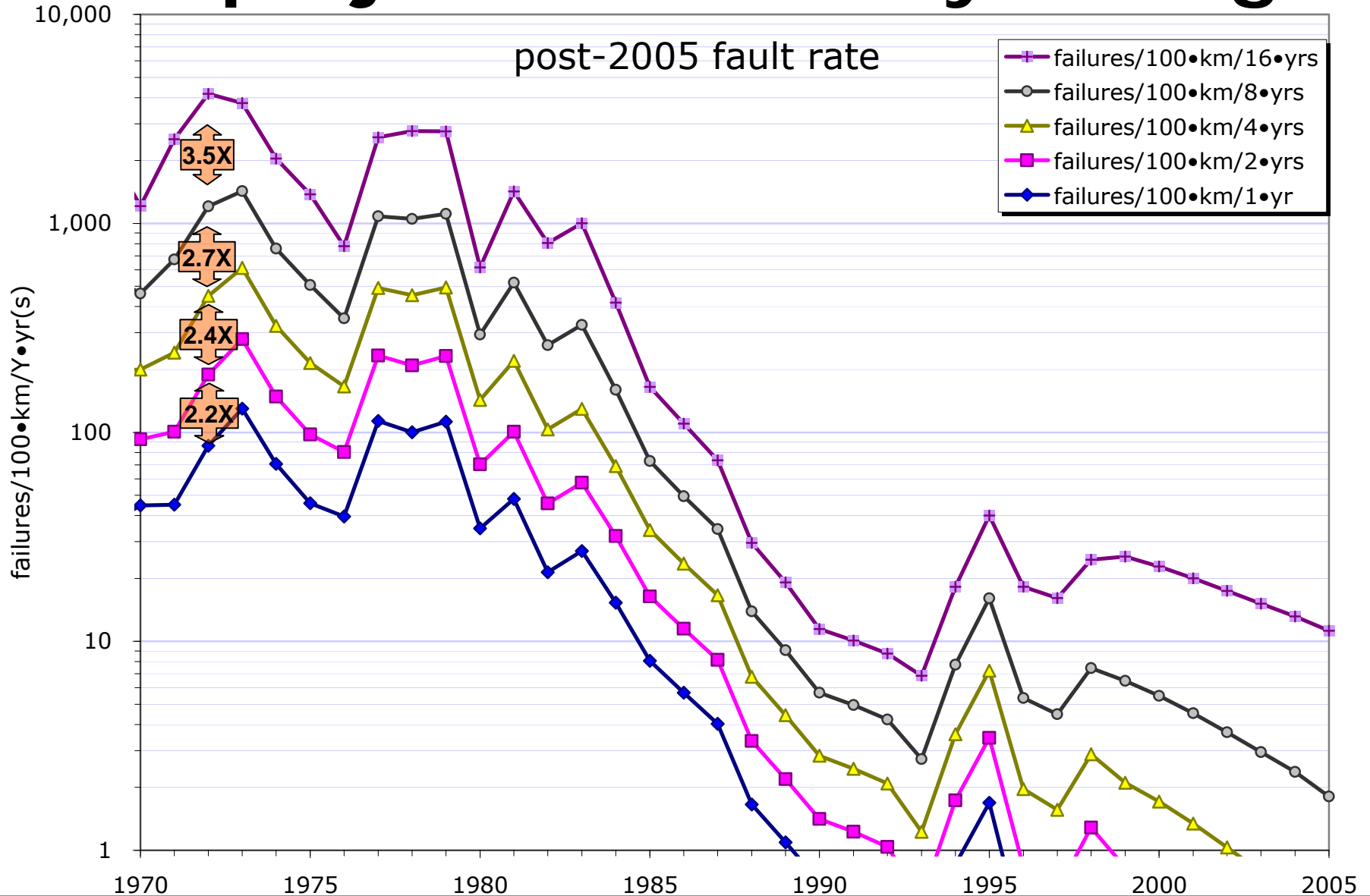
# Historical Data & Agglomerated C-A

- post-2000
- 1991-2000
- 1986-1990
- 1981-1985
- 1976-1980
- pre-1975
- Actual (total)
- Actual (<'81)
- Actual (<'76)

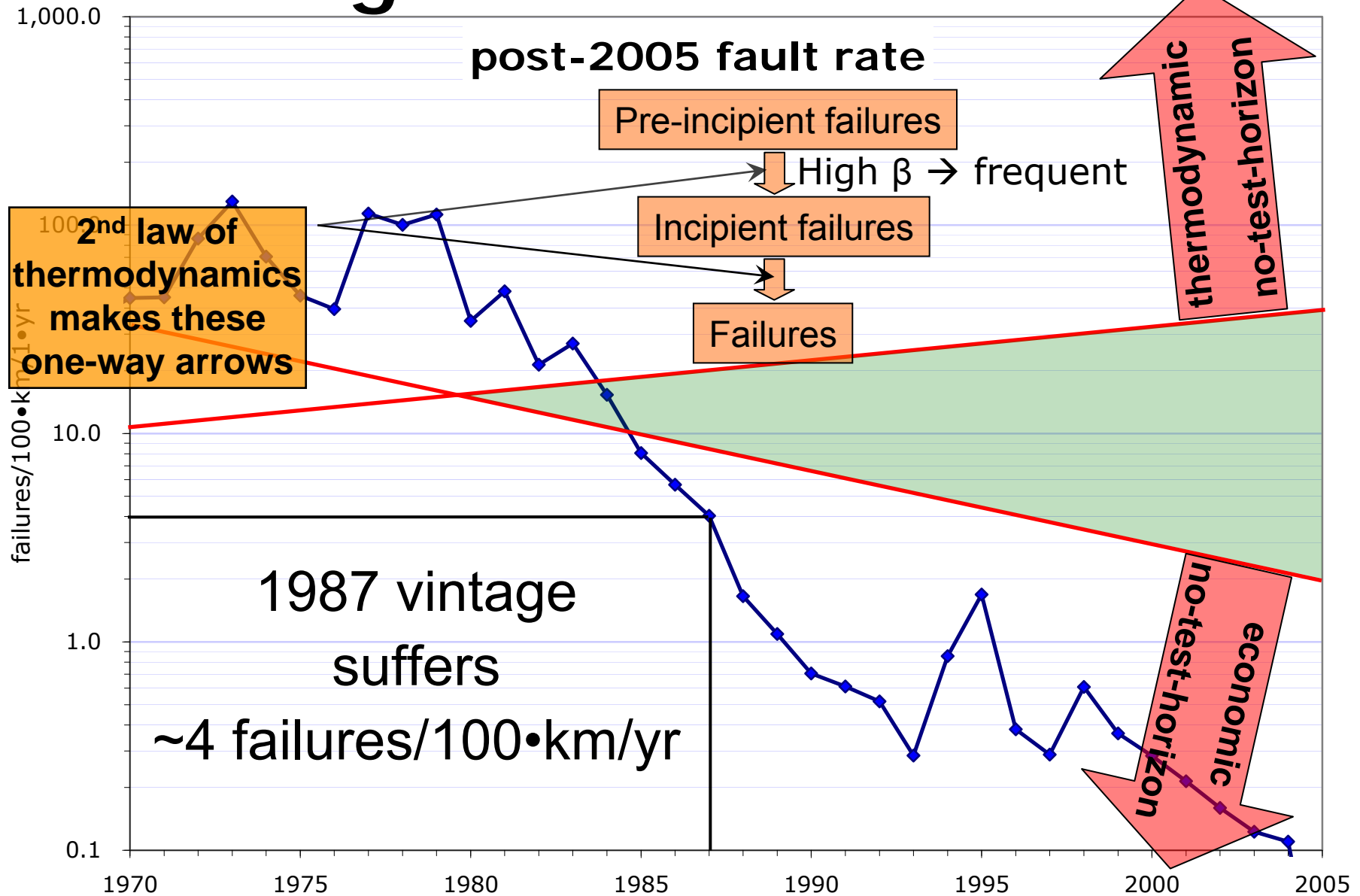
Annual Failures



# C-A projected faults by Vintage



# Diagnostic Conundrum



# Cost of URD Failure

● Complaints	\$100
● Troublemaker restores power	\$800
● Dispatch utility locators	\$200
● Dispatch fault repair crew	\$2,000
● PUC performance-based-ratemaking fine	\$800
<hr/>	
● Fault Repair Total	\$3,900

# NPC to ignore 100 km of 1987 vintage cable

Assumptions:		\$3,900	3%	11%
Year	Failures /cKm/Yyrs	NPC	Inflation factor	discount factor
1	4.0	\$14,301	1.03	0.89
2	4.1	\$13,437	1.06	0.79
3	4.2	\$12,618	1.09	0.70
4	4.3	\$11,842	1.13	0.63
<b>Total</b>		<b>\$52,198</b>		

# Diagnostic Testing Costs

## 2 elements

- Direct costs \$4/meter (\$1.22/ft) or \$400k to test 100 km
- Consequential costs
  - Cost to replace identified “bad” cables (this is between 20% and 45% of the tested population as in [6])
  - Testing induced failures (including testing induced false negatives; [6] indicates 5% over 6 year period)

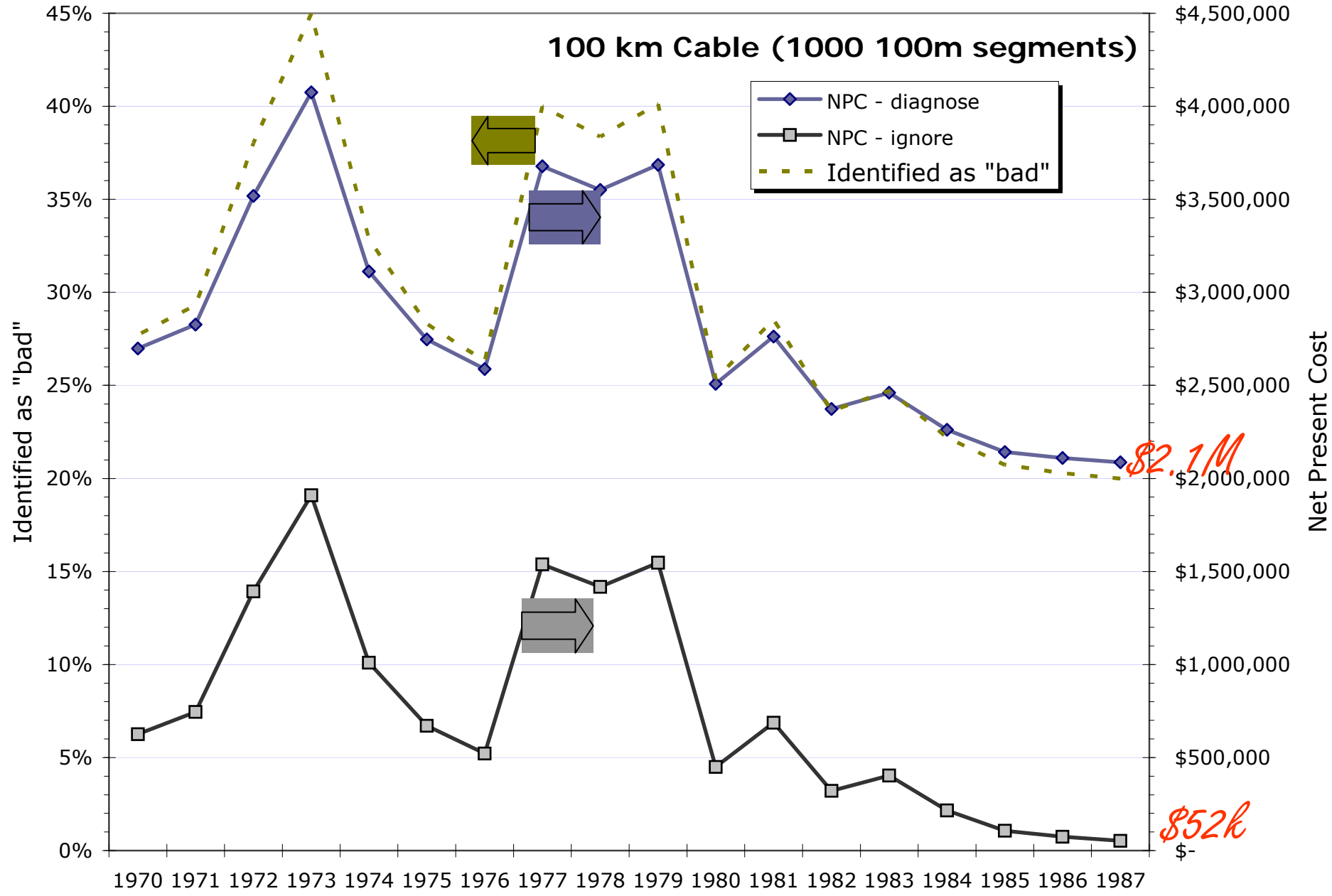
# Consequential Costs of Testing

Year	Assumptions			
	20%	1%	\$3,900	\$7,954
	Identified as "bad"	Testing induced failures	Failure NPC	Replacement NPC <i>\$24.25/ft</i>
0	200			\$ 1,590,800
1		2.5	\$ 8,938	\$ 18,229
2		2.5	\$ 8,193	\$ 16,710
3		2.5	\$ 7,511	\$ 15,318
4		2.5	\$ 6,885	\$ 14,042
<b>Subtotal:</b>			<b>\$ 31,527</b>	<b>\$ 1,655,099</b>
<b>Total:</b>			<b>\$1,686,626</b>	

*+ \$400k direct cost*

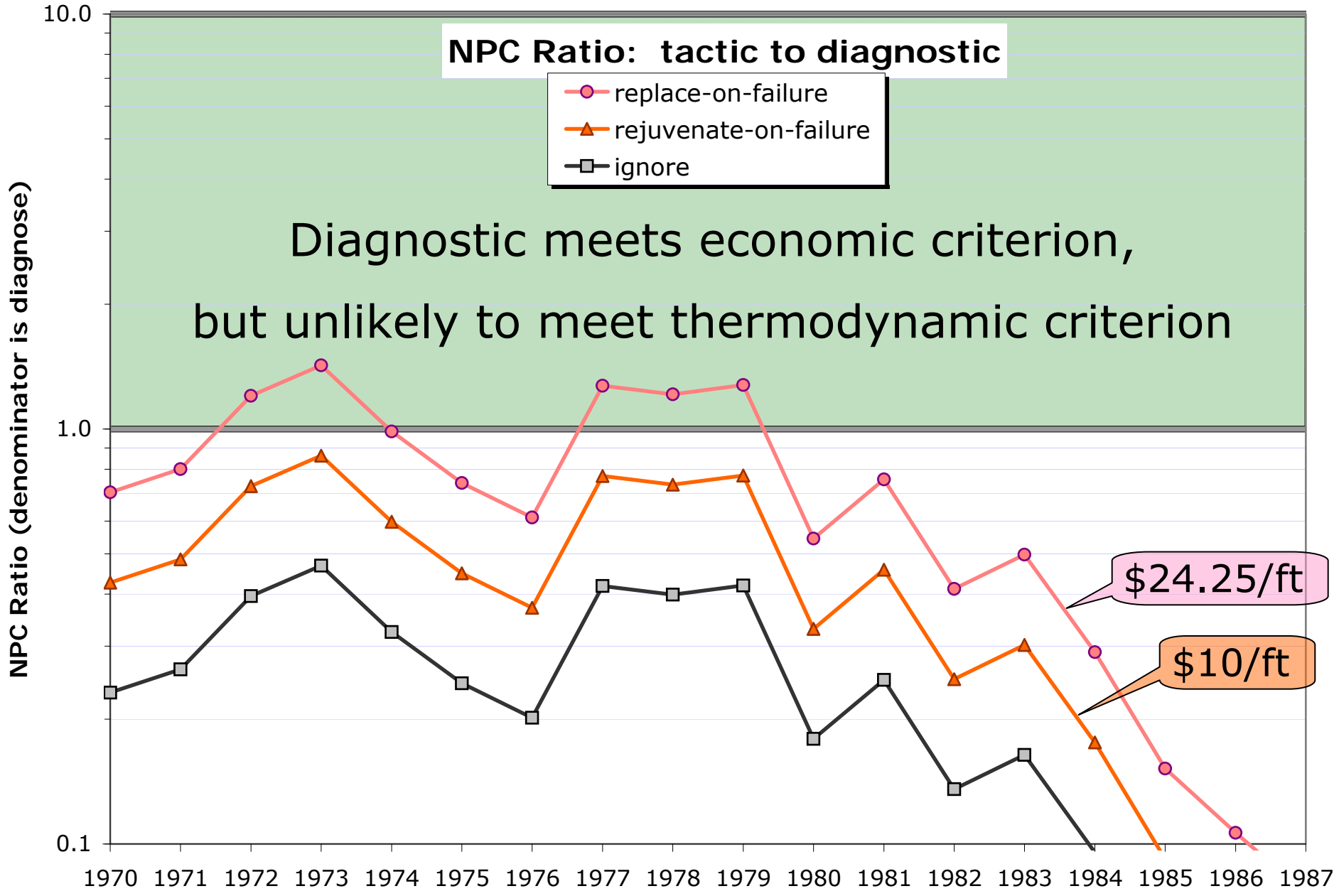
*\$2.1M total*

### 100 km Cable (1000 100m segments)



*\$2.1M*

*\$52k*



# Thermodynamic Criterion

## Required Experiment

- population
  - Reasonable homogeneous
  - Statistically significant
  - Divided into 2 sub-populations
- Apply off-line diagnostic to sub-pop-1; apply on-line diagnostic to sub-pop-1 and sub-pop-2
- Track failures for several years
- No such study has ever been undertaken
- Anecdotal results are not encouraging
- For high  $\beta$  ...
  - HV off-line tests are too destructive
  - On-line testing requires too frequent retesting

Pre-incipient failures



High  $\beta$  → frequent

Incipient failures



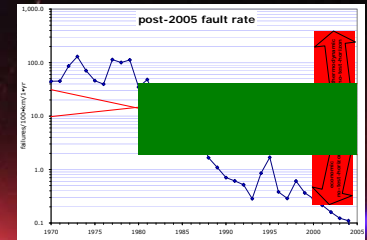
Failures

**All is not lost...**

# Stochastic Diagnostic

- C-A statistics cost less ( $<15\text{¢}/\text{ft}$ )
  - Modest sample size
  - Tolerant of sampling error
- 3 kinds of data required ...
  - Vintage cable segment installation records
  - Cable failure records tied to vintage
  - Replacement & rejuvenation records

# Summary



- Economics preclude testing “good” cable
- thermodynamics precludes testing “bad” cable
  - Pre-incipient faults are not detectable
  - Pre-incipient faults → incipient faults
- C-A statistics → required strategic view