Recent Progress in US Nuclear Power Plant Safety

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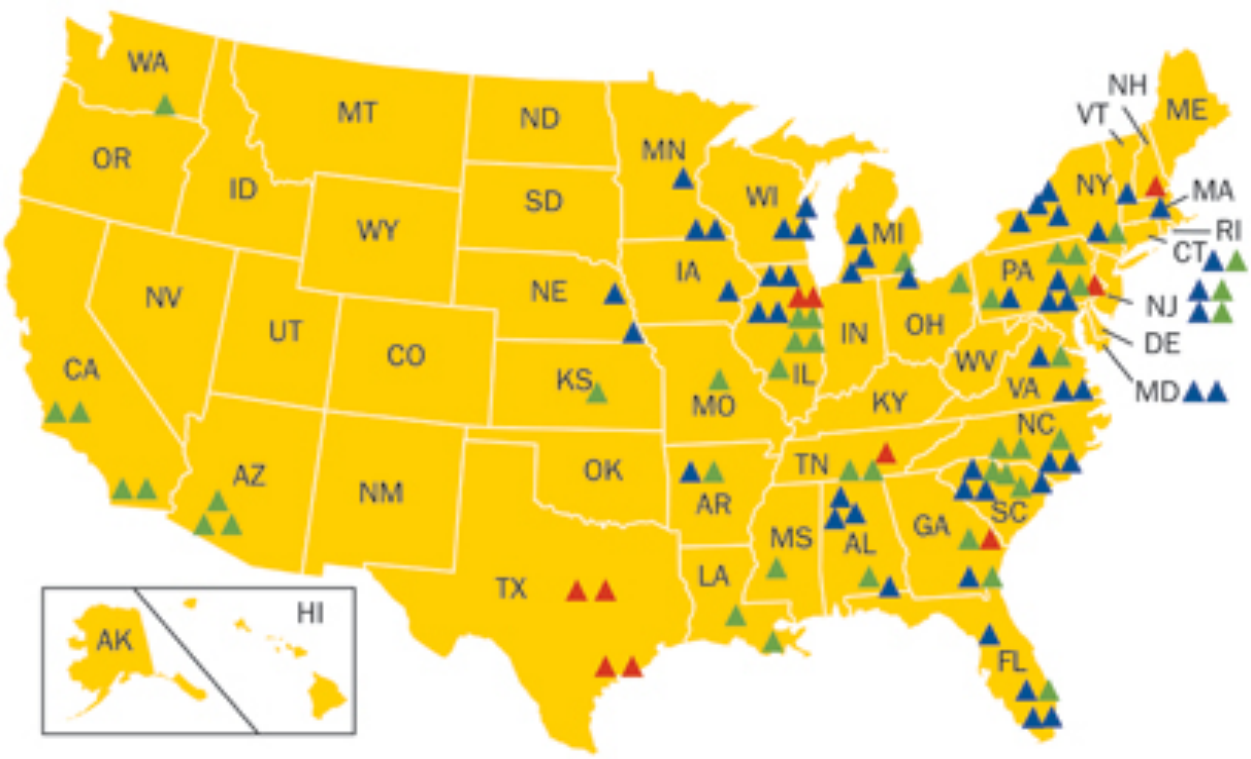
104 U.S. nuclear power plants

U.S. Commercial Nuclear Power Reactors—Years of Operation



Years of Commercial Operation	Number of Reactors
△ 0-9	0
▲ 10-19	10
▲ 20-29	42
▲ 30-39	52

Source: U.S. Nuclear Regulatory Commission

Three questions vis-à-vis nuclear power plants

- How is “safety” achieved?
- How is “safety” analyzed or measured?
- Why do we believe that safety has improved significantly in the last decade or so?

What characterizes a "safe" nuclear power plant?

Answer: It is a plant whose probability (in a given year) of a major accident is "acceptably low".

This raises a question – How "low" is "acceptably low"?

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The US NRC has given us guidance on this:

Core Damage Frequency	≤	about 10^{-4} per year
Large Release Frequency	≤	about 10^{-6} per year

Analyzing “safety”

This raises a second question -- How does one analyze CDF and LRF?

Answer: One requires a safety assessment, which intrinsically must be probabilistic, a so-called “PRA” (“probabilistic risk analysis”).

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Specifically:

- **Postulate every initiator, and determine its frequency**
- **Work out the contingent probability of "core damage" given the initiator**
- **Work out the consequences of each sequence**

A major “problem”:

We have hardly any “accidents” to use for benchmarking.

[This is a triumph for engineering, but a “problem” for the analyst charged with figuring out what the (low) accident frequencies might be.]

How to measure the "safety" that is actually achieved?

- Overall analysis of entire reactor (probabilistic)
- System-specific analysis
- Analysis of "precursors"
- Safety "indicators"

In practice ….

- Overall design
- Quality of construction
- Operations including human factors
- Safety “culture” (including “continuous improvement”)
- How does “continuous improvement” work in practice?

Safety Philosophy

- Redundant systems
- Lots of “margin” in each engineering facet
- Well-trained operating crew
- Learning from experience (world-wide)
- No-fault reporting

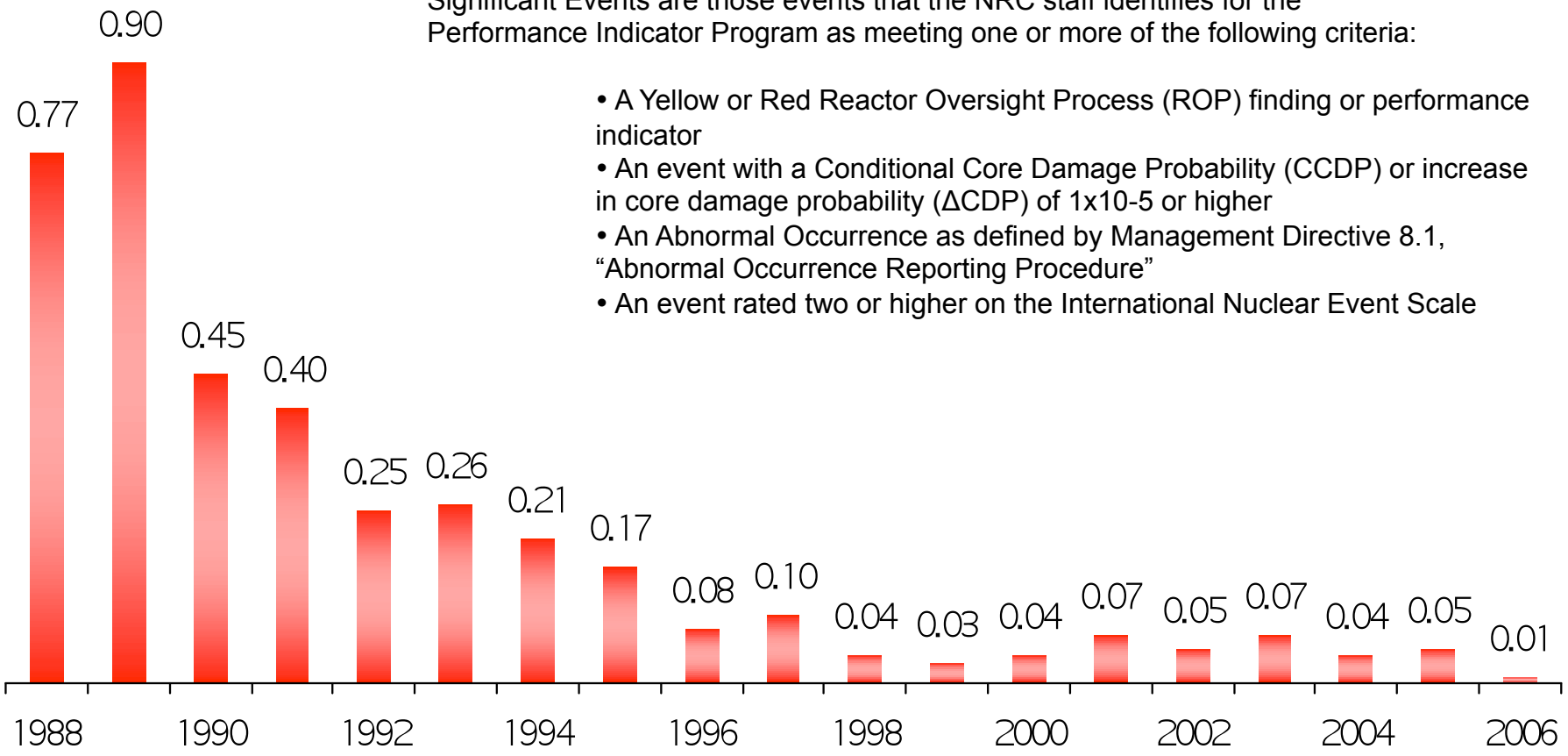
Next, look at the data

Significant Events at U.S. Nuclear Plants:

Annual Industry Average, Fiscal Year 1988-2006

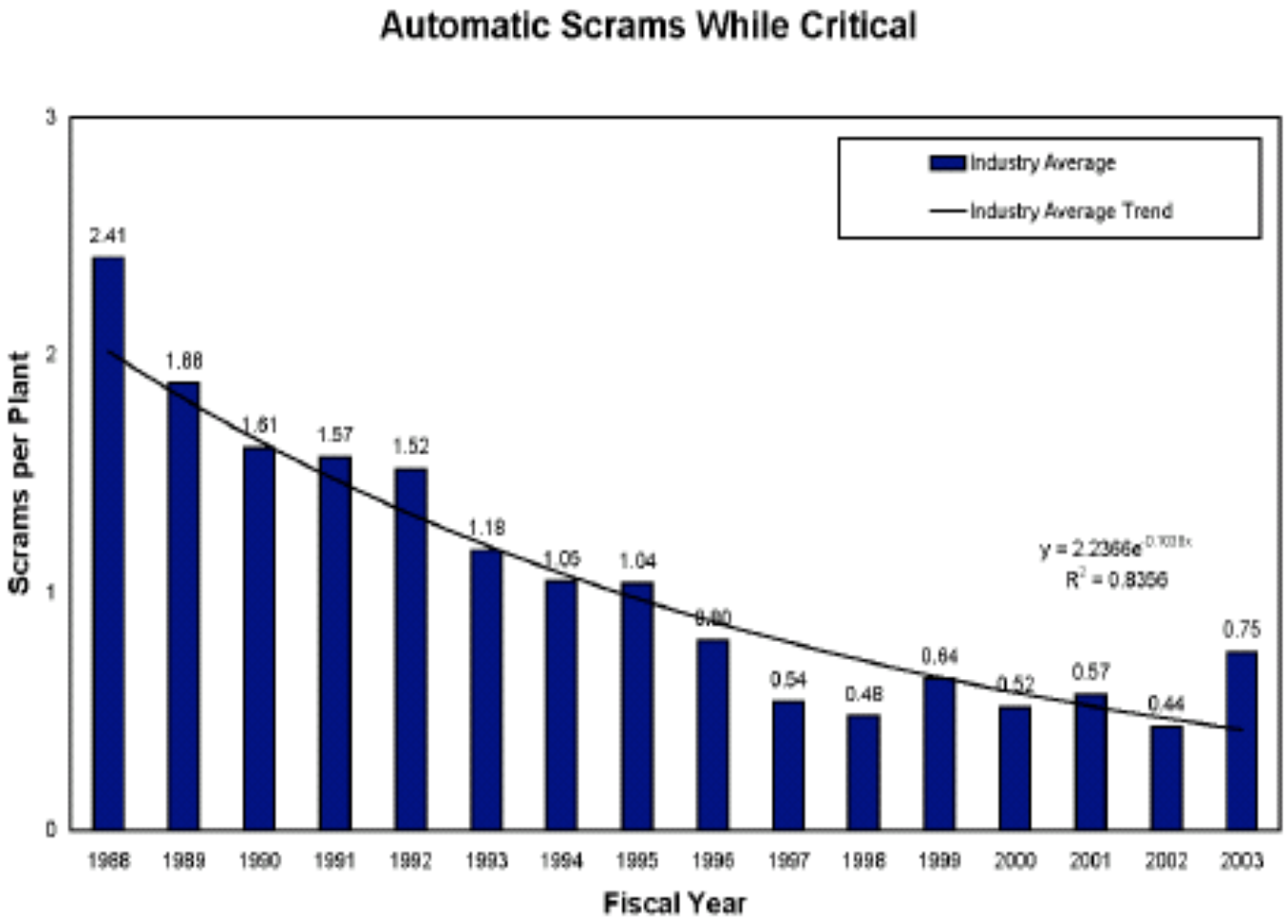
Significant Events are those events that the NRC staff identifies for the Performance Indicator Program as meeting one or more of the following criteria:

- A Yellow or Red Reactor Oversight Process (ROP) finding or performance indicator
- An event with a Conditional Core Damage Probability (CCDP) or increase in core damage probability (ΔCDP) of 1x10-5 or higher
- An Abnormal Occurrence as defined by Management Directive 8.1, "Abnormal Occurrence Reporting Procedure"
- An event rated two or higher on the International Nuclear Event Scale

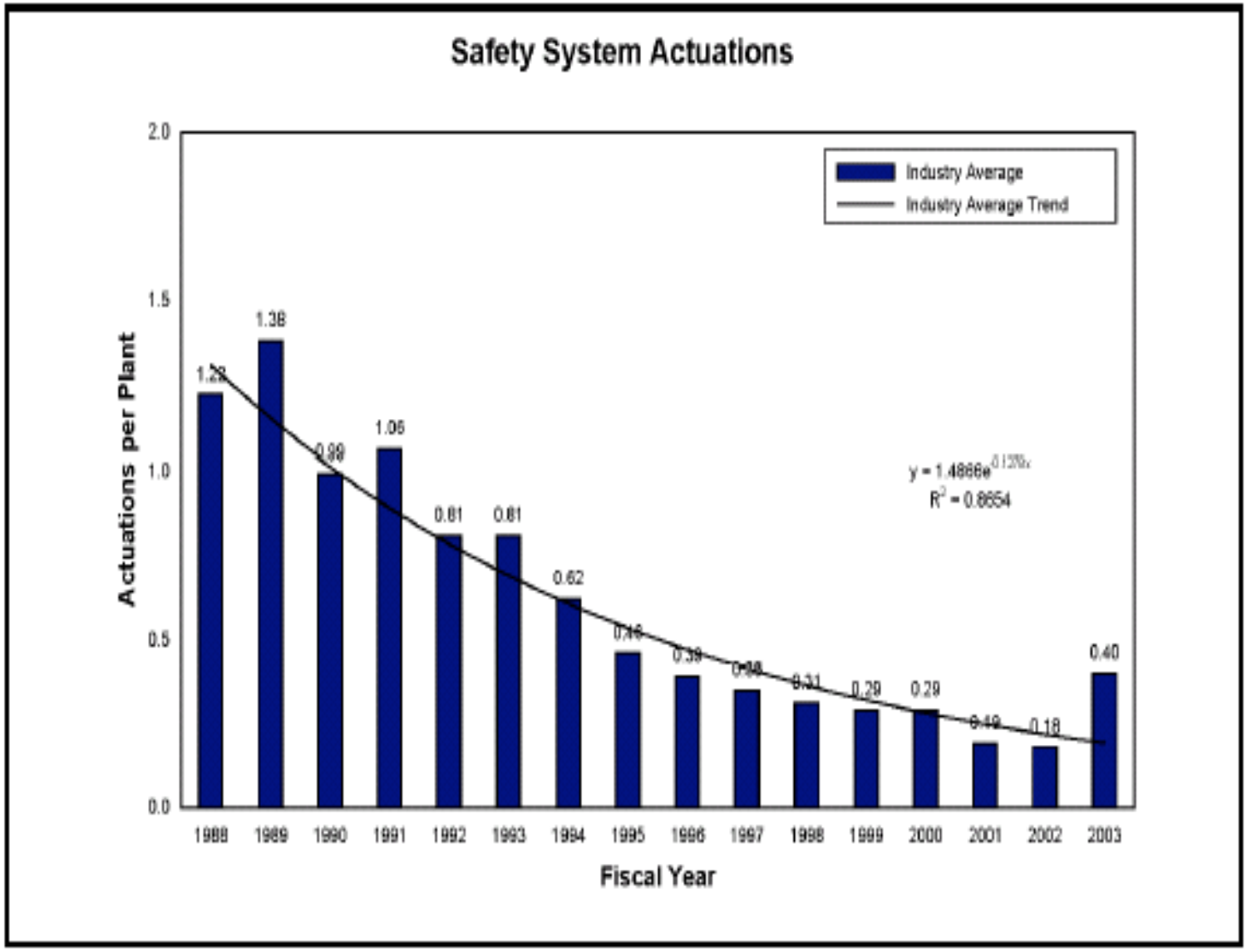


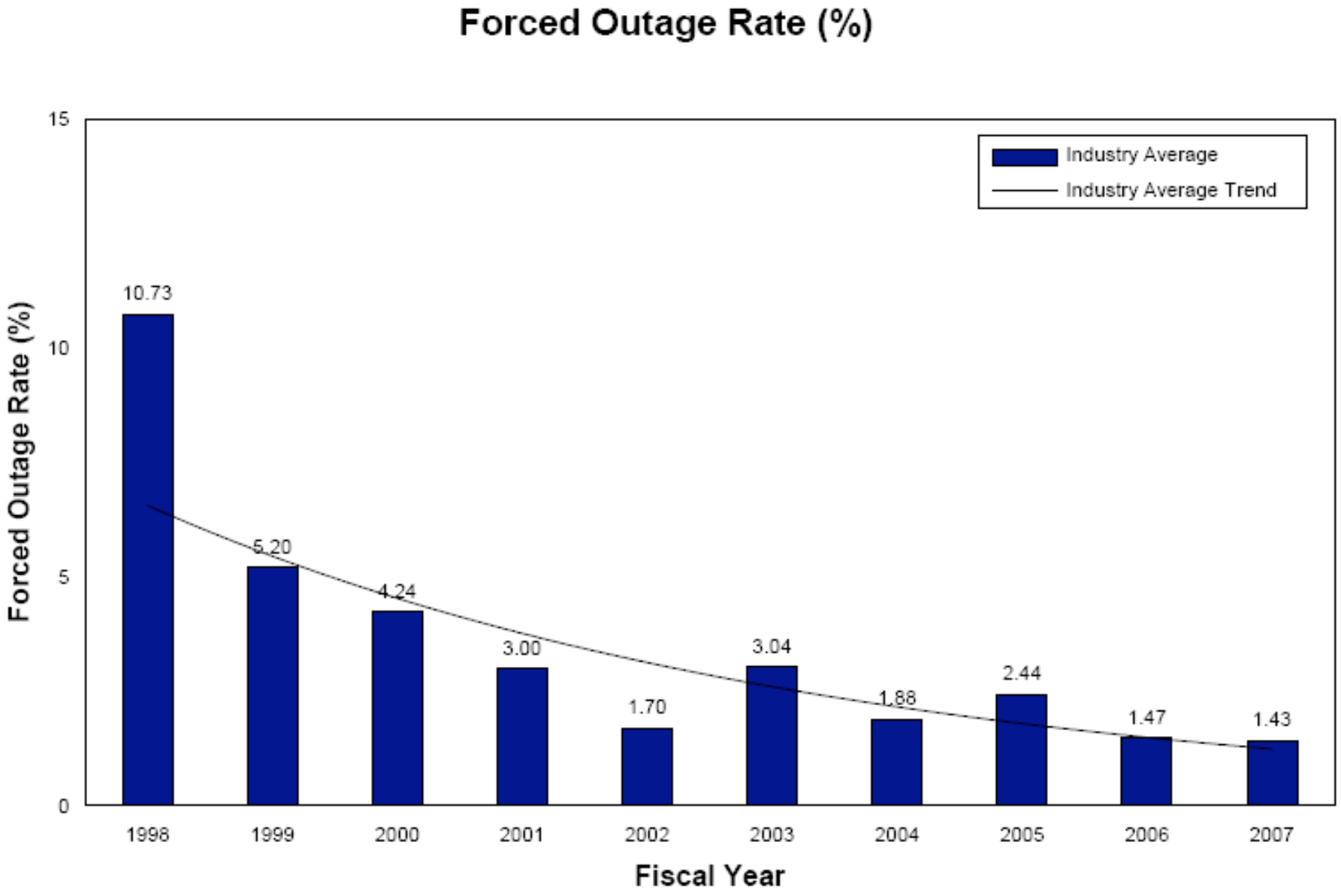
Source: NRC Information Digest, 1988 is the earliest year data is available.
Updated: 11/07

Budnitz note:
in 2006, the figure was 0.32 per plant
in 1985 it was 4.2
in 1980 it was 7.3




Safety System Failures
Industry Average
Industry Average Trend
Failures per Plant
0
1
2
3
4
2.76
1.68
1.40
0.83
0.87
0.96
0.78
0.99
0.59
0.65
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Fiscal Year


Safety System Actuations
Industry Average
Industry Average Trend
Actuations per Plant
Fiscal Year
2.0
1.5
1.0
0.5
0.0
1.38
1.06
0.99
0.81
0.81
0.62
0.40
0.29
0.29
0.18
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003


Forced Outage Rate (%)
Industry Average
Industry Average Trend
Forced Outage Rate (%)
15
10
5
0
10.73
5.20
4.24
3.00
1.70
3.04
1.88
2.44
1.47
1.43
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Fiscal Year

Safety – What accounts for these trends?

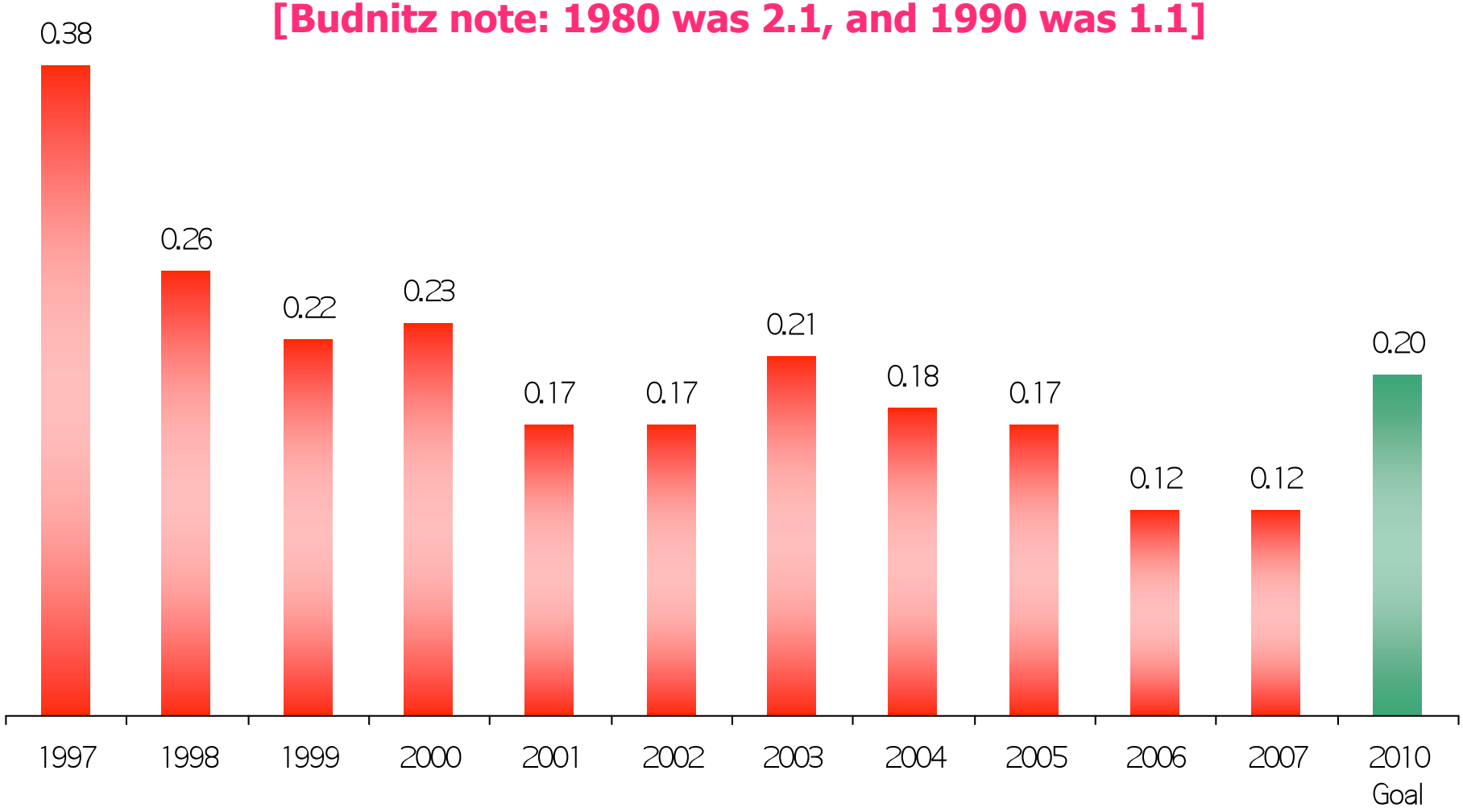
- **Learning from experience: industry-wide reporting system**
  - **Reporting everything to everybody, no fault**
- **Analysis: major effort to analyze each event for its causes, implications**
- **Maintenance: concentrating on the important things, design for easier maintenance**
- **Operator errors: simulator training, procedures**
- **Industry-wide peer-to-peer inspection visits, task forces**
- **Design changes: eliminating design flaws, a "forgiving" design**
- **NRC: Risk-informed enforcement actions (ignore minor events)**

Let’s look at
industrial safety and costs

U.S. Nuclear Industrial Safety Accident Rate

One-Year Industry Values

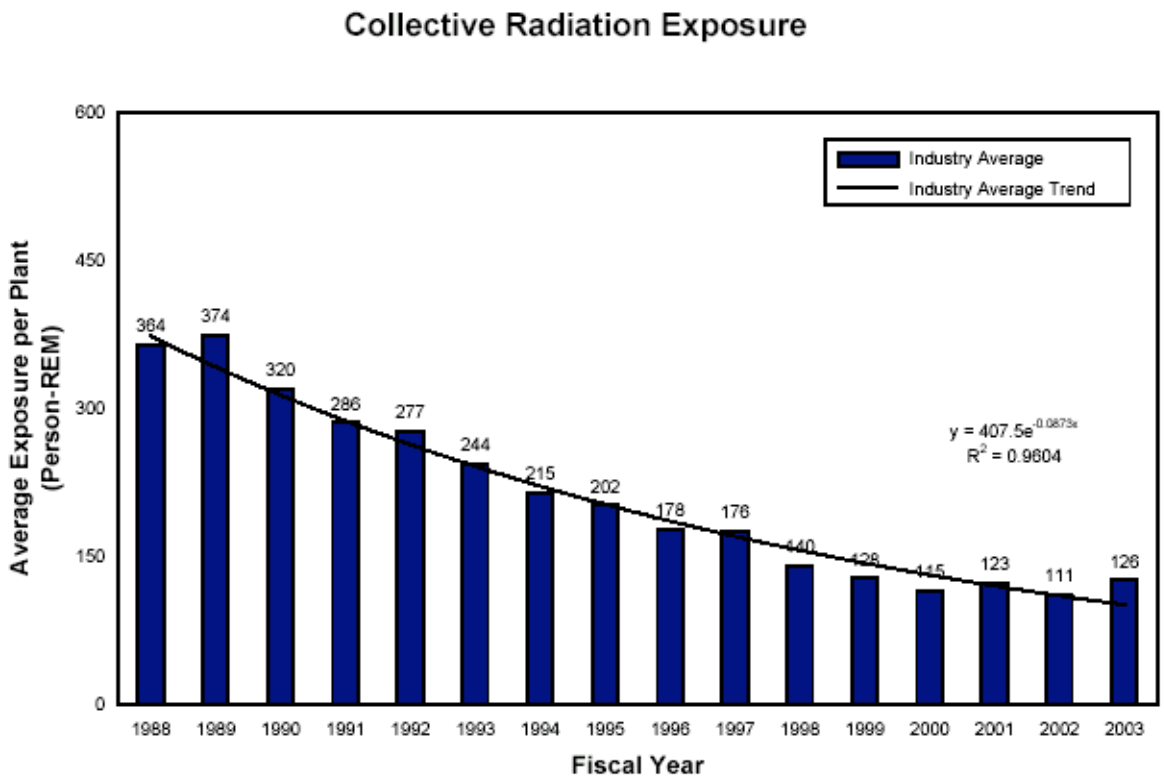
[Budnitz note: 1980 was 2.1, and 1990 was 1.1]



ISAR = Number of accidents resulting in lost work, restricted work, or fatalities per 200,000 worker hours.

Source: World Association of Nuclear Operators
Updated: 4/08

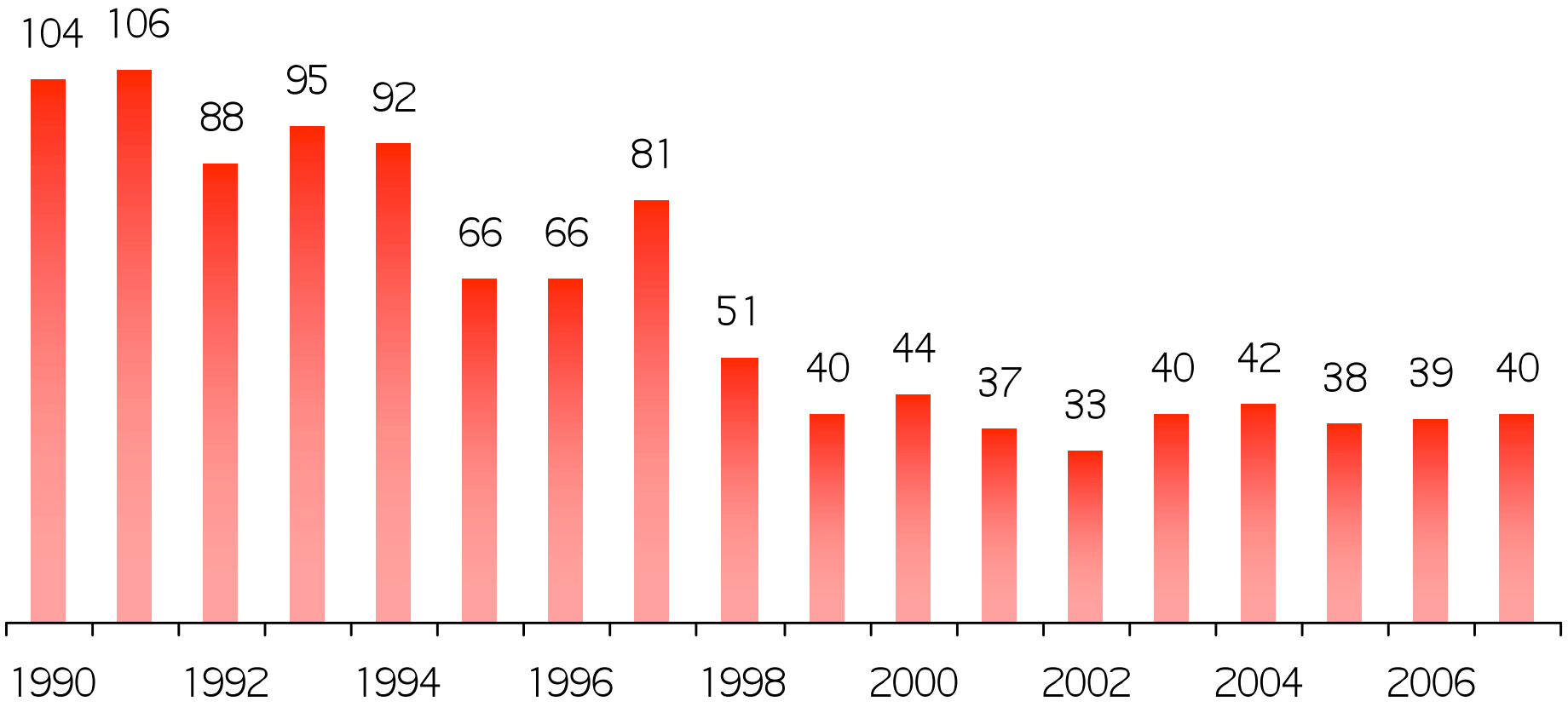
(Budnitz note: in 2006, the figure was 93 person-rem/plant)



Costs are dropping too

- **The cost of nuclear-produced electricity is dominated by the capital cost of building the reactor plant.**
- **For today's reactors, that is all sunk cost.**
- **Major change: The operating costs and fuel costs have been declining rapidly.**

U.S. Nuclear Refueling Outage Days Average

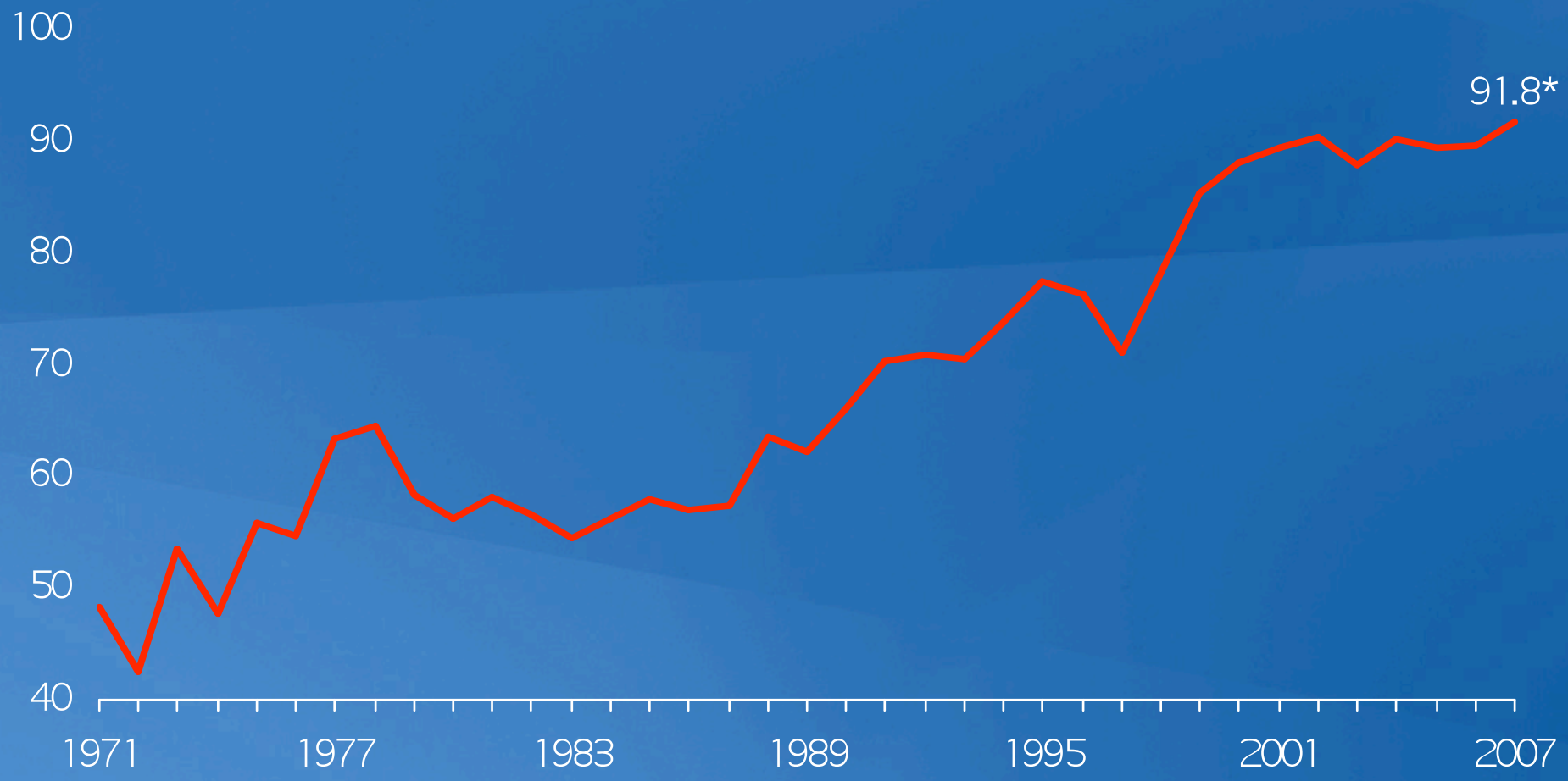


Source: 1990-98 EUCG, 1999-2007 Energy Velocity / Nuclear Regulatory Commission

Updated: 2/08

U.S. Nuclear Industry Capacity Factors

1971 - 2007



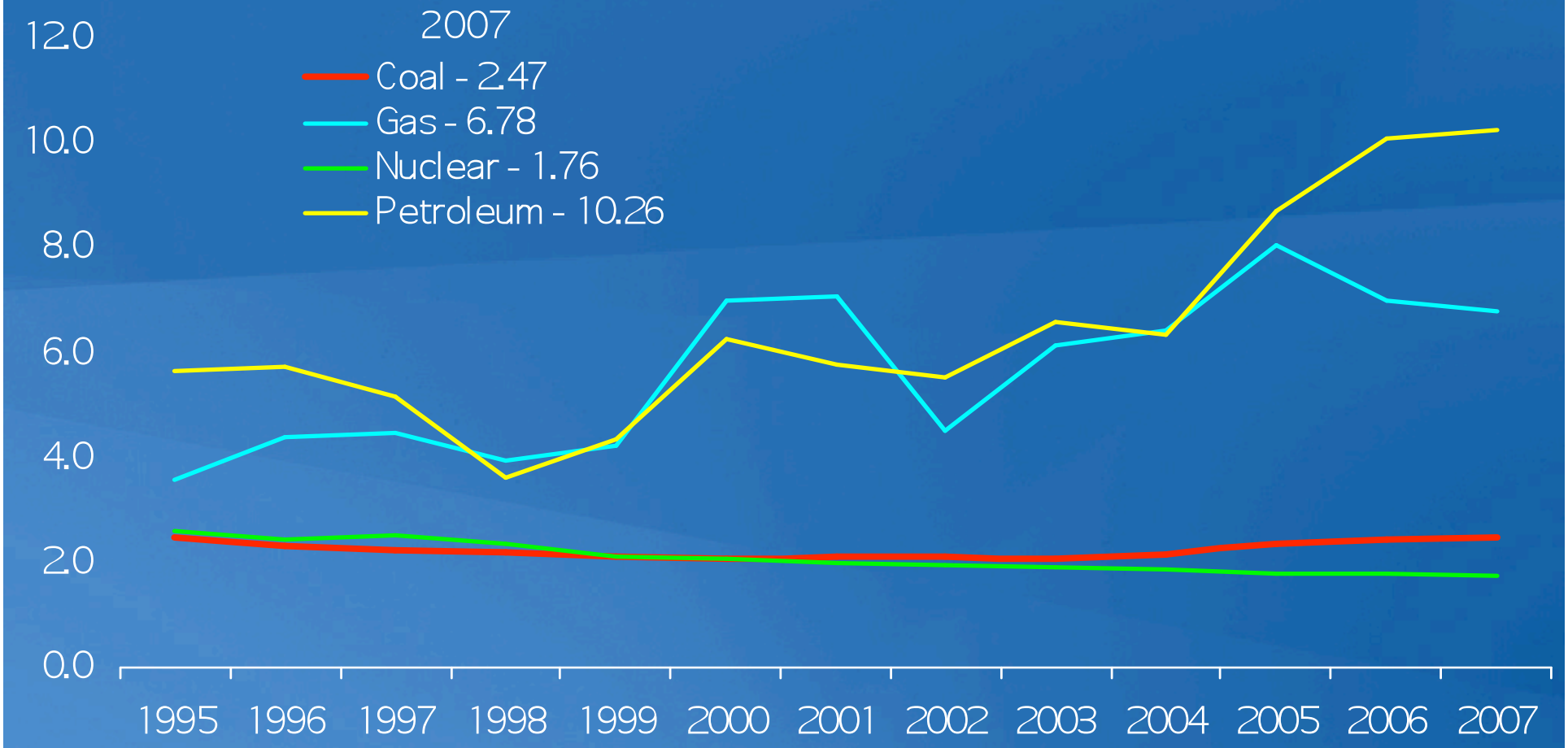
* Preliminary

Source: Global Energy Decisions / Energy Information Administration

Updated: 4/08

U.S. Electricity Production Costs

1995-2007, *In 2007 cents per kilowatt-hour*

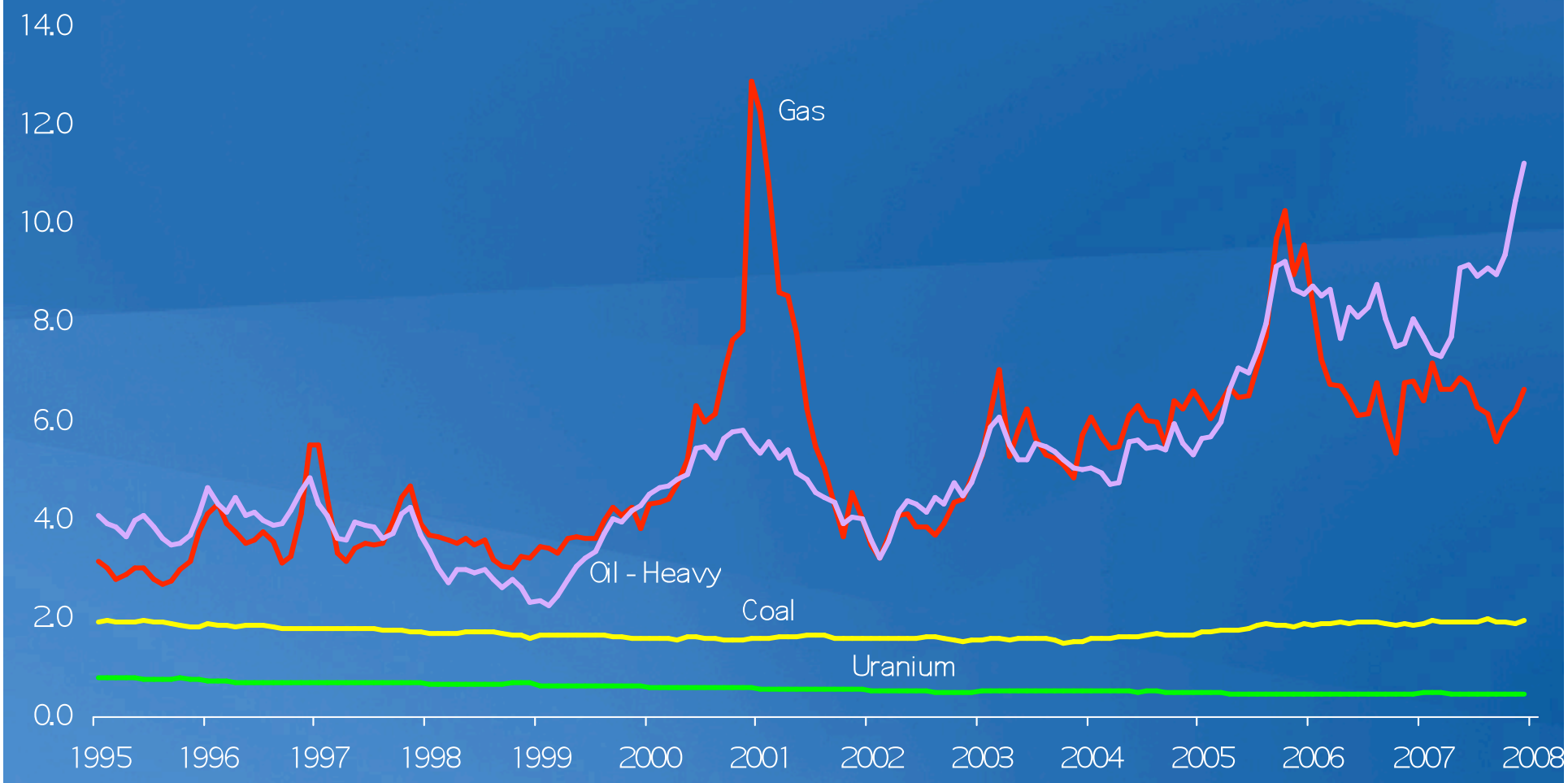


Production Costs = Operations and Maintenance Costs + Fuel Costs

Source: Global Energy Decisions
Updated: 5/08

Monthly Fuel Cost to U.S. Electric Utilities

1995 – 2007, *In 2007 cents per kilowatt-hour*

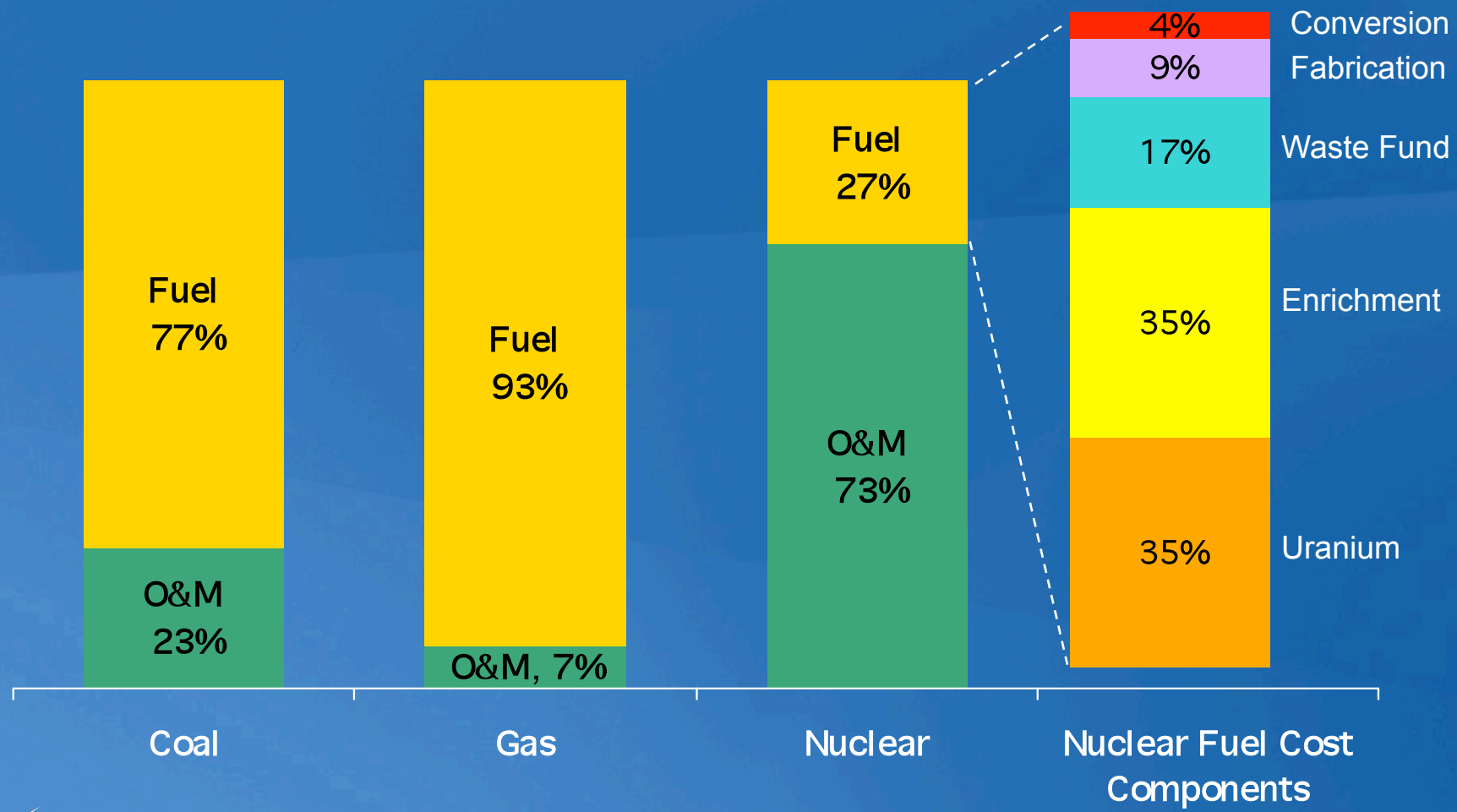


Source: Global Energy Decisions

Updated: 5/08

Fuel as a Percentage of Electric Power Production Costs

2007



Source: Global Energy Decisions; Energy Resources International, Inc.
Updated: 5/08

Safety -- Key Attributes

- safety culture
- safety culture
- safety culture

(trained crews, learning from experience, no-fault reporting, analysis, feedback from experience)

- a "forgiving" design

Security

- against outside attack
- against insider sabotage
- against theft of nuclear material