Problem Of The Month
July 1997--Monte Carlo Reliability Model Starting With WinSMITH Weibull Data

WinSMITH Weibull software can assemble random data into a very compact form. The software will provide a useful probabilistic information for many purposes as was illustrated in the March '97 problem of the month. This problem shows how to estimate the fatigue life of a pressure vessel--in this case a very large diameter coke drum.

The next question is "What can you do with the information"? Answers for questions below are graphically illustrated with GIF files for clarity--these six files are 122 K in size and may take a few moments to load.

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Background

Refer to the background information for the March '97 problem of the month to show how stress data is converted into a statistical format for a process which is behaving in a probabilistic manner.

Monte Carlo modeling is a numerical method of solving engineering problems by random sampling. The method usually involves complicated problems in various areas such as reliability engineering, queuing theory, nuclear engineering, astrophysics, agriculture, and the list goes on. The generally accepted public birth date for Monte Carlo methods is 1949 with an article published by J. von Neumann and S. Ulam. The Monte Carlo method was used in classified projects during the Manhattan Project studies of the atomic bomb in the early 1940s where random numbers were chosen from tables prepared by statisticians working on WPA projects during the depression years of the early 1930s--remember we haven't had computers forever!

The name Monte Carlo comes from the roulette wheel at the Monte Carlo casino in Monaco. The roulette wheel is considered one of the simplest mechanical devices for generating random numbers.

The Monte Carlo method requires some sort of an algorithm for computation. A random number is drawn and the algorithm computed. The process is repeated N times with each trial being independent of every other trial. From the randomness comes order and a central value is derived.

The Monte Carlo method always has errors. Errors are proportional to (D/N)^0.5 where D is some constant. By inspection, you can see that if you want to add a decimal point change (i.e., a factor of 10) then you need to increase N by a factor of 100. That means you need many iterations to achieve accuracy.

Many arguments occur about the "goodness" of the random number generator. For practical purposes, the random number generator in most modern PCs is pretty good and certainly good enough for solving practical engineering problems where we're trying to achieve answers to 10% accuracy or better. We'll save the perfect answer for the scientist to find--if they can live long enough.

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The Problem

Discrete stress measurements of circumferential and axial stress on coke drums can be used to improve coke drum design by converting the experimental data into a statistical format. This technique was shown in the March '97 problem of the month using high temperature experimental stress data from Richard Boswell of Stress Engineering Services in Houston, TX.

Actual stresses collected during normal operation of coke drums at ~900F (480C) can be used to simulate future expected stress loads on the drum. Each drum is expected to exhibit its own unique stress patterns and locations based on operating conditions, etc. which requires a physical stress assessment of actual conditions over a period of 6-12 months to calibrate the model.

The stress simulations follow accepted Monte Carlo techniques from the field of reliability. Results of the simulation, which is calibrated by actual field conditions, can be used to forecast end of life by fatigue or by rupture based on typical stress distributions and a valid S-N curve.

Questions:

1) How will the algorithm be established for finding the life of a coke drum which is a pressure vessel with high thermal and crushing stresses randomly imposed on the stresses from internal pressure?

2) Using experimental stresses collected on the surface of coke drum what is the expected life?

3) How does wall thickness vary with end of life under these stress loading conditions?

4) What effect would limiting the stresses have on fatigue life?

5) If stresses are limited, how many cutbacks can production expect based on a specified stress level.

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Solutions:

Answer to Question 1) How will the algorithm be established for finding the life of a coke drum which is a pressure vessel with high thermal and crushing stresses randomly imposed on the stresses from internal pressure?

Figure 1 shows a coke drum model starting with actual experimental stresses and the S-N curve expected for the material. The methodology is shown in the lower left hand corner of the figure. By randomly selecting stresses to simulate the stresses which would occur during operation, a case history is forecasted by simulation to calculate end of fatigue life.

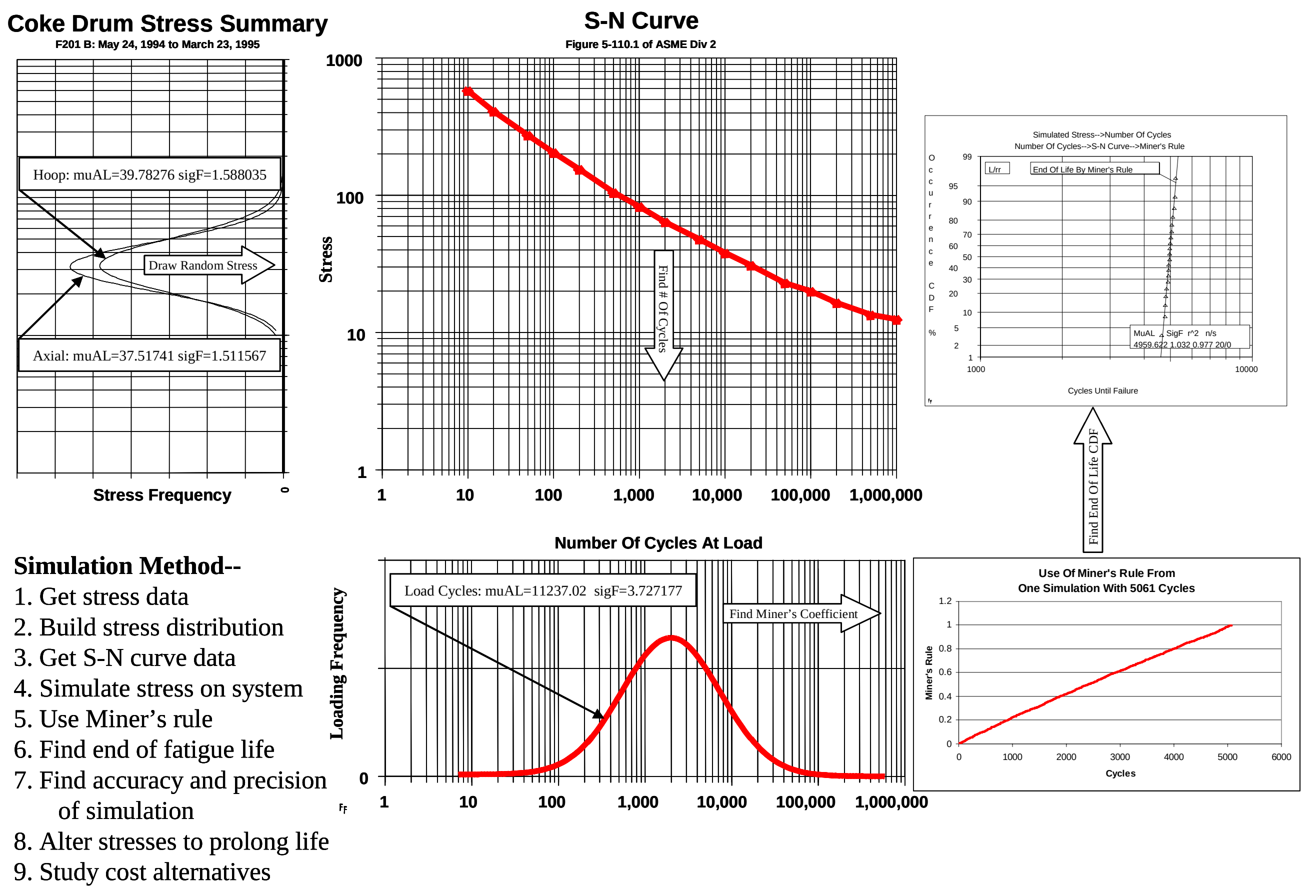
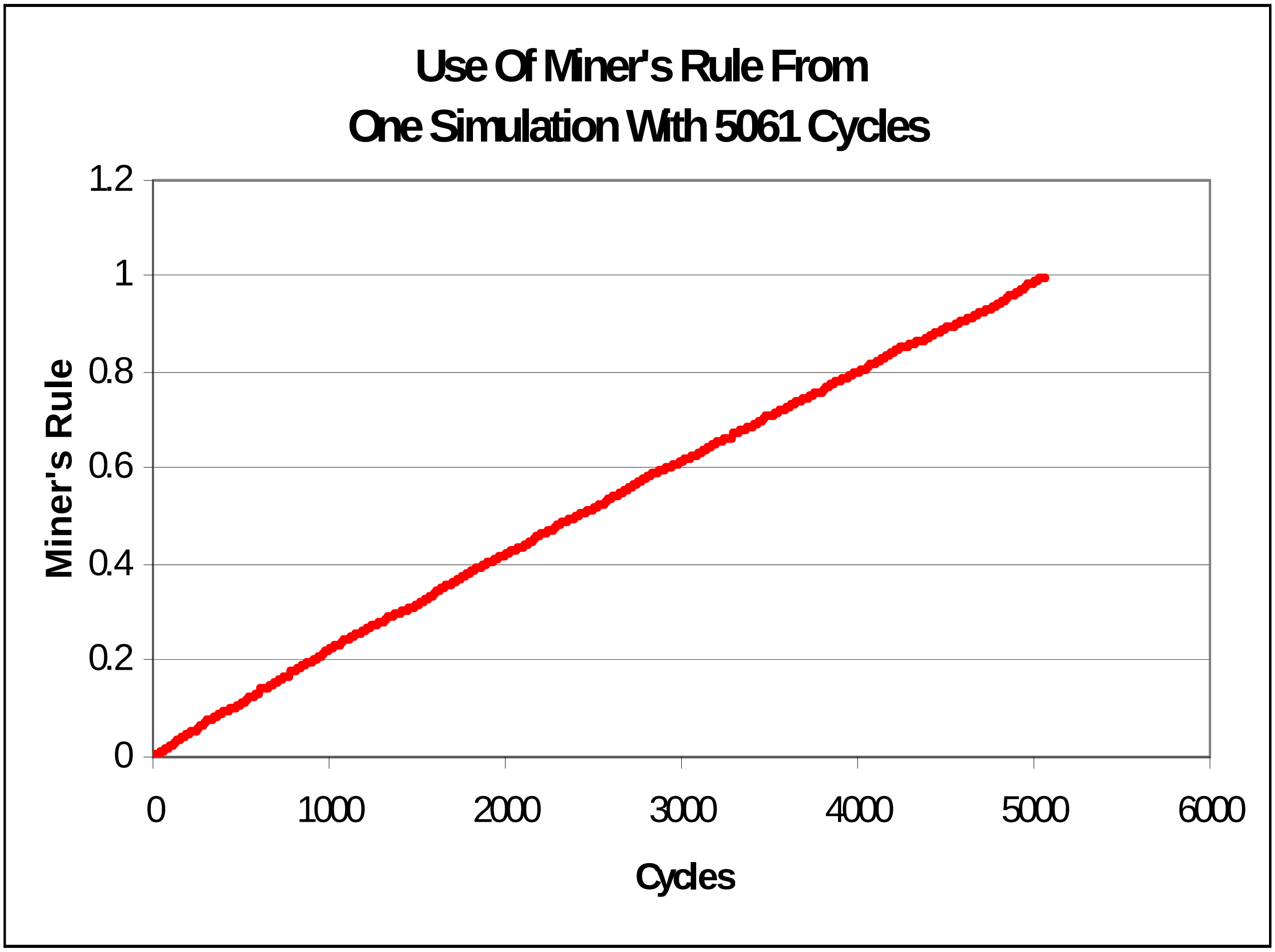


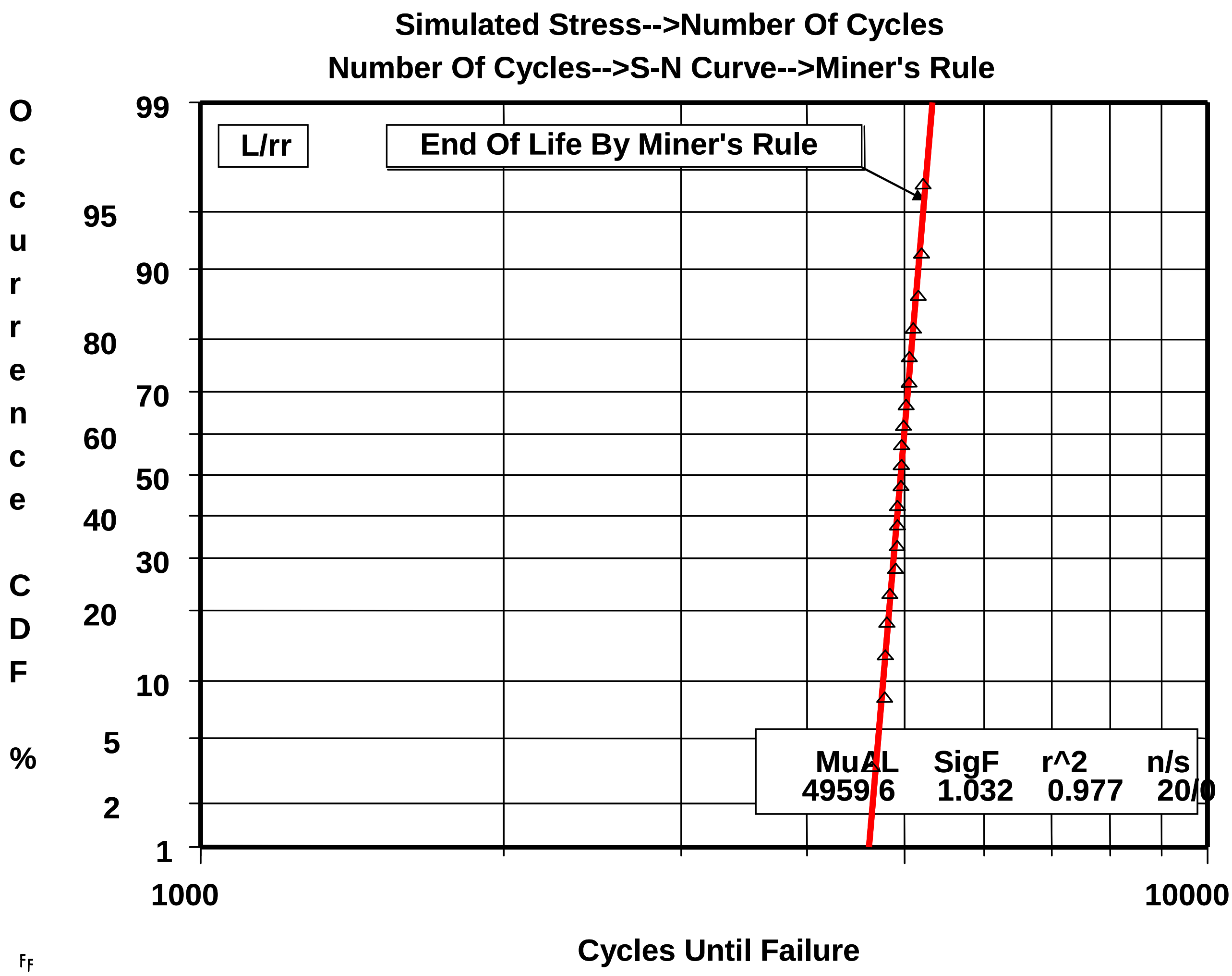
Figure 1: Steps For Building A Coke Drum Reliability Model

Answer to Question 2) Using experimental stresses collected on the surface of coke drum what is the expected life?

Using Miner's rule for fatigue stresses, individual load steps are accumulated until Miner's rule sums to 1.0 for fatigue failure. For this specific case, fatigue life is reached at 4960 cycles ±~350 cycles based on use of Miner's rule for fatigue--of course end of life by rupture will be longer. For this particular model, the chronological age to failure is 27.6 years. The figure below shows one example of how Miner's rule accumulates by Monte Carlo simulation as the actual curve oscillates around the straight line until it reach end of life at the failure point of 1.0. This curve was generated from a Monte Carlo simulation using Mircrosofts Excel 97. End of life for this Monte Carlo run occurred after 5061 cycles. This figure is shown in the bottom right hand side of Figure 1.



The Monte Carlo process is repeated 20 times to find end of life--that's 20*~5000 individual calculations. Central tendency results are shown for the end of life at 4960 cycles. This figure is shown in the upper right hand side of Figure 1.



Answer to Question 3) How does wall thickness vary with end of life under these stress loading conditions?

Figure 2 shows an example of using the model to forecast wall thickness requirements for a variety of cycles until end of life. The thickness requirements are helpful for design of new drums or repair of damaged sections. For this case, adding 20% to the wall thickness would double the number of cycles until reaching the fatigue limit.

Answer to Question 4) What effect would limiting the stresses have on fatigue life?

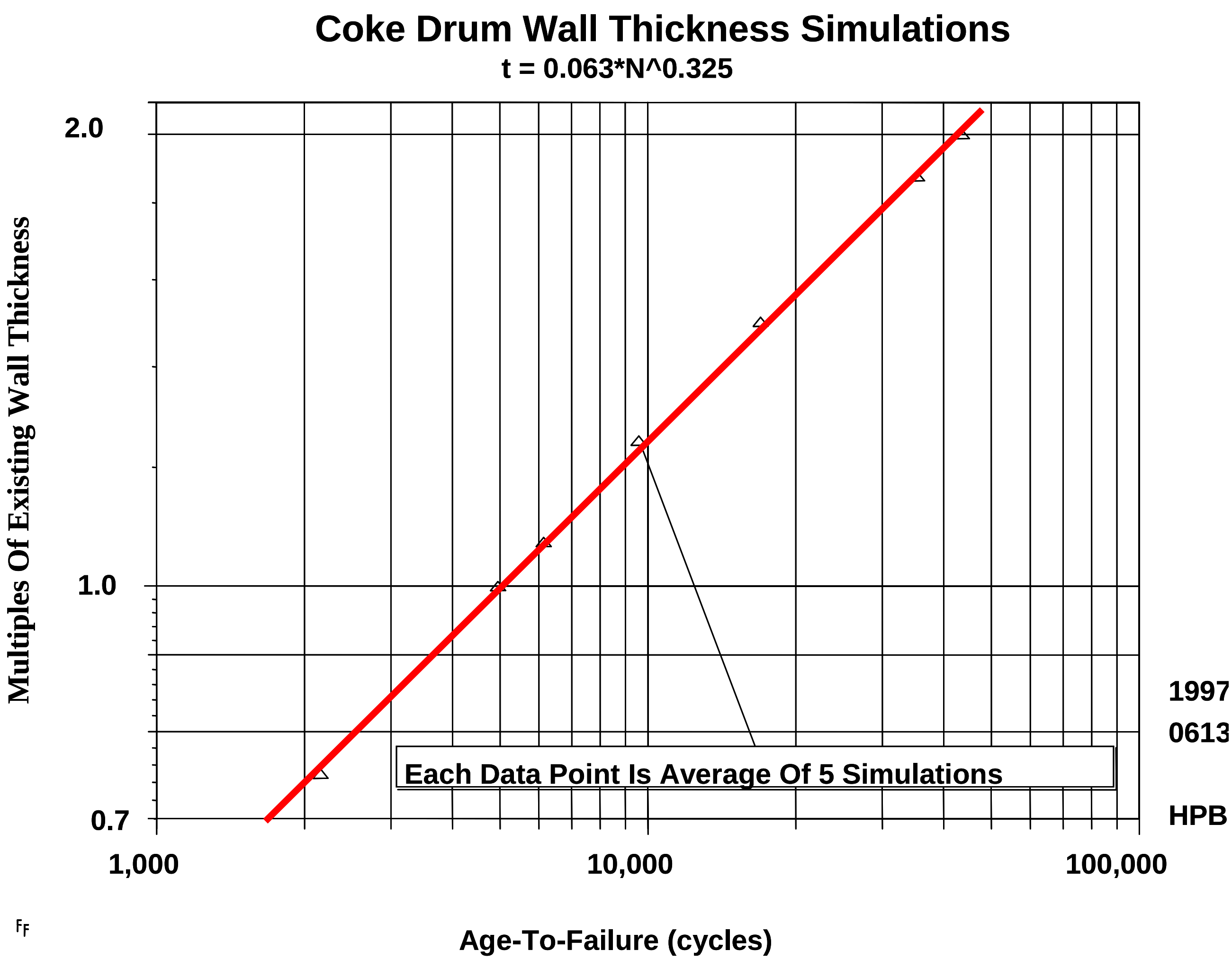


Figure 2: Coke Drum Wall Thickness Vs Cycles To End Of Life

Limiting peak drum stresses is another alternative to increase fatigue life. This alternative requires continuously monitoring the drum and moderating peak operating conditions by minutes/hours to avoid life-robbing peak stresses. This condition can help extend life of existing drums by projecting the end of life under present conditions and forecasting the improvement by stress control procedures by simulation modeling as shown in Figure 3.

Answer to Question 5) If stresses are limited, how many cutbacks can production expect based on a specified stress level.

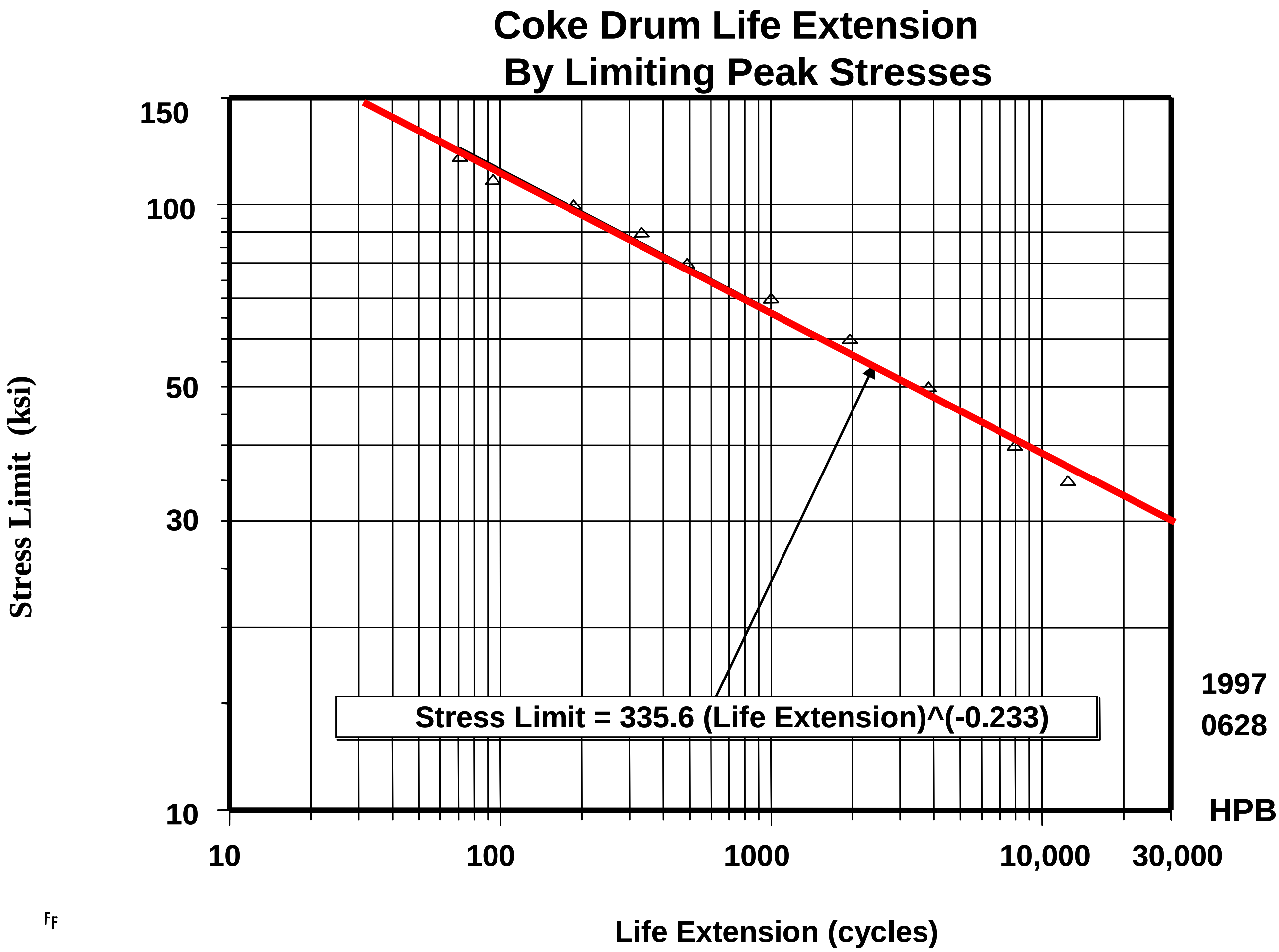


Figure 3: Coke Drum Life Extension By Limiting Peak Stresses

Figure 4 shows the number of normal cycles per cutback expected when a maximum stress level is specified.

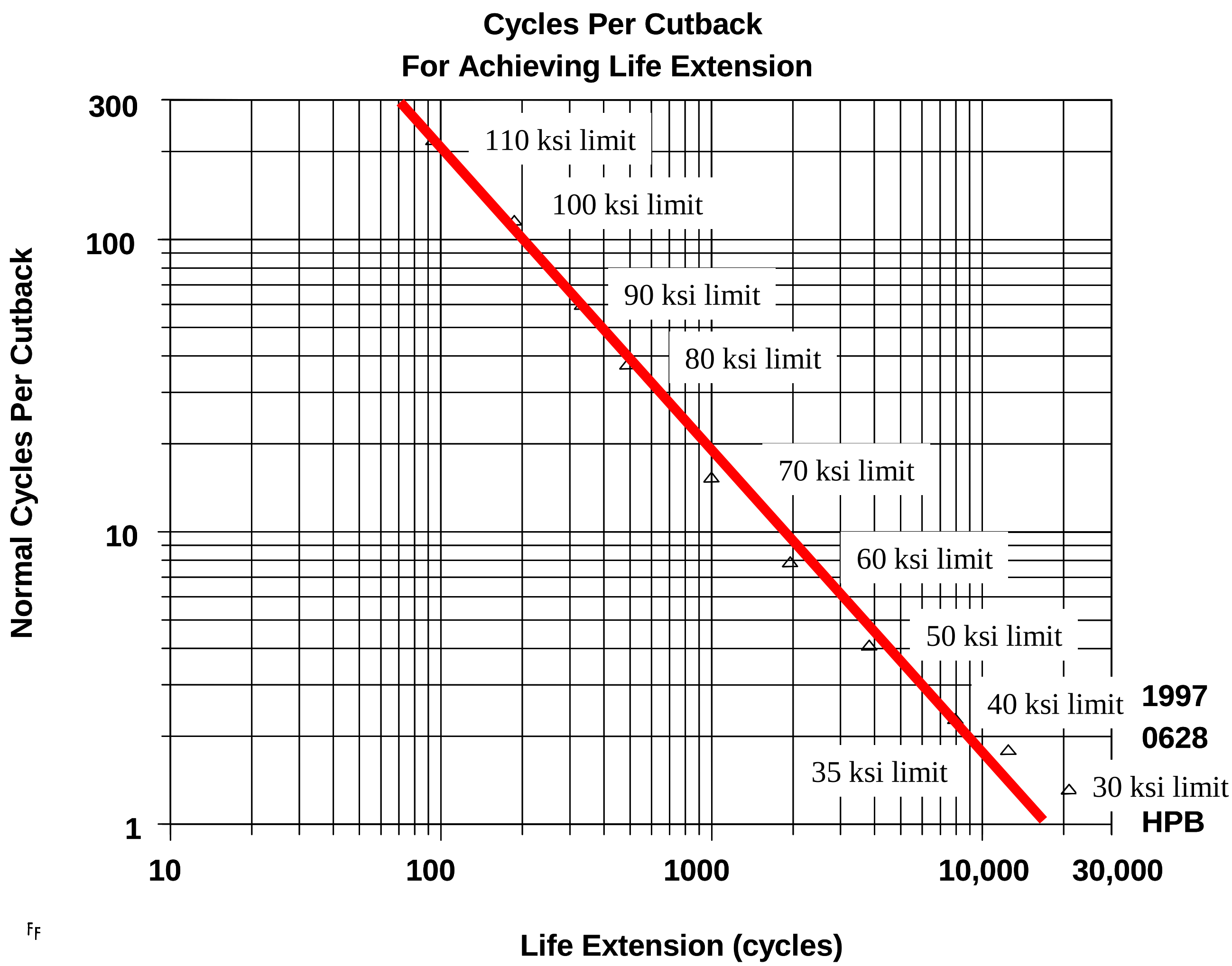


Figure 4: Production Cutbacks By Limiting Peak Stresses

Of course the final question involves life cycle costing to find cost-effective actions to arrive at a solution most effective for the stockholders.

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Other Industry Sources For Coke Drums-

Technical comments distributed on a CD to an American Petroleum Industry conference on coke drums in May 2001 are available at http://www.stress.com/servicetier3.php?sid=5&pid=206 by Stress Engineering Services who perform experimental stress analysis and conduct extensive FEA computer studies of coke drums.

CIA Inspection Inc. performs extensive inspection of the interior of on-line delayed coke drums without blinding or scaffolding to obtain a detailed interior profile of the vessel using laser range imaging and video inspection. The site has links to coke drum related sites.

Comments:
Here are a few quotations that might make this idea about Monte Carlo methods palatable:

If you bet on a horse, that's gambling.
If you bet you can make three spades, that's entertainment.
If you bet the structure will survive for a hundred years, that's engineering.
See the difference? **Ephraim Suhir**, *Applied Probability for Engineers and Scientists*, McGraw-Hill, 1997, page xix.

The man with a new idea is a crank until the idea succeeds. **Mark Twain** *Following the Equator,* ch. 32, "Pudd'nhead Wilson's New Calendar" (1897).

Traditional scientific method has always been at the very *best,* 20-20 hindsight. It's good for seeing where you've been. It's good for testing the truth of what you think you know, but it can't tell you where you *ought* to go. **Robert M. Pirsig** *Zen and the Art of Motorcycle Maintenance,* pt. 3, ch. 24 (1974).

The real accomplishment of modern science and technology consists in taking ordinary men, informing them narrowly and deeply and then, through appropriate organization, arranging to have their knowledge combined with that of other specialized but equally ordinary men. This dispenses with the need for genius. The resulting performance, though less inspiring, is far more predictable. **John Kenneth Galbraith** *The New Industrial State,* ch. 6 (1967).

Refer to the caveats on the **Problem Of The Month Page** about the limitations of the above solution. Maybe you have a better idea on how to solve the problem. Maybe you find where I've screwed-up the solution and you can point out my errors as you check my calculations. E-mail your comments, criticism, and corrections to: Paul Barringer by **clicking here**.

Technical tools are only interesting toys for engineers until results are converted into a business solution involving money and time. Complete your analysis with a bottom line which converts $'s and time so you have answers that will interest your management team!

You can download this problem as a PDF file by clicking here.

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